Volume 22 JULY, 1938 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

Stratigraphy of Coastal Plain of Georgia
By C. Wythe Cooke and Arthur C. Munyan 789

Recent Petroleum Activities in Coastal Plain of South Georgia
By A. C. Munyan 794

Oil and Gas Possibilities in Atlantic Coastal Plain from New Jersey to Florida
By Olive C. Postley 799

Scanlan, or Midway, Dome, Lamar County, Mississippi *By D. J. Munroe* 816

Application of Principle of Differential Settling to Tracing of Lenticular Sand Bodies *By John L. Rich* 823

Criteria for Determining the Time of Accumulation Under Special Circumstances *By Stanley C. Herold* 834

Stratigraphy of the Bendian of the Oklahoma Salient of the Ouachita Mountains *By Bruce H. Harlton* 852

GEOLOGICAL NOTES

Possible Nature of Limestone Reservoirs in the Permian Basin *By H. P. Bybee* 915

Subsurface Study of Cherokee Formation Near Kansas City, Missouri *By Glenn G. Bartle* 918

Upper Paleozoic Chinati Series, Presidio County, Texas *By John W. Skinner* 924

DISCUSSION

Custer Formation of Texas *By Leroy T. Patton* 925

Deepest Rocks at Jackson, Mississippi *By Watson H. Monroe* 927

REVIEWS AND NEW PUBLICATIONS

Regionale Geologie der Erde (Regional Geology of the Earth), edited by K. Andrèe, H. A. Brouwer, and W. H. Bucher *By R. D. Reed* 929

Palaeozoic Formations in the Light of the Pulsation Theory, Vol. III, Cambrovician Pulsation System, by Amadeus W. Grabau *By Byron N. Cooper* 934

Recent Publications 936

THE ASSOCIATION ROUND TABLE

Membership Applications Approved for Publication 940

Mid-Year Meeting, El Paso, Texas, September 27-October 2, 1938 943

Association Committees 945

AT HOME AND ABROAD

Current News and Personal Items of the Profession 946

Copyright, 1938, by The American Association of Petroleum Geologists, Inc.

CABLE TOOL OPERATORS

DON'T WORK IN THE DARK ...TRYING TO ANALYZE MERE BAILER SAMPLES...

The complete, uncontaminated Cores consistently recovered with a Baker Cable Tool Core Barrel will "throw light" on what you want to know about formations penetrated, such as . . .

POROSITY
PERMEABILITY
SATURATION
GRAIN SIZE
COMPOSITION

You will also like the ease, efficiency and operating economy of this dependable tool.
Write today for complete details or see the Baker Section of your 1938 Composite Catalog.

BAKER Cable Tool Core Barrel

BAKER OIL TOOLS, INC.

Telephone JEfferson 8211 – HUNTINGTON PARK, CALIFORNIA – 2959 E. Slauson Ave.
Telephone WAyside 2108 – HOUSTON PLANT AND OFFICE – 6023 Navigation Blvd.
MID-CONTINENT OFFICE AND WAREHOUSE:
Telephone 2-8083 – Tulsa, Oklahoma – 312 East Fourth Street
WEST TEXAS BRANCH OFFICE Odessa, Texas – Telephone 217
EXPORT SALES OFFICE Rm. 1914 – 19 Rector St. New York City Tel. Digby 4-5515
ROCKY MOUNTAIN HEADQUARTERS Tel. 2230-Casper, Wyoming – Box 1466

BAKER **CABLE TOOL CORE BARREL**

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, 608 WRIGHT BUILDING, TULSA, OKLAHOMA

WALTER A. VER WIEBE, *Editor*

GEOLOGICAL DEPARTMENT, UNIVERSITY OF WICHITA, WICHITA, KANSAS

ASSOCIATE EDITORS

GENERAL	K. C. HEALD, Gulf Oil Corporation, Box 1166, Pittsburgh, Pa.
	HUGH D. MISER, U. S. Geological Survey, Washington, D. C.
	THERON WASSON, Room 2308, 35 E. Wacker Drive, Chicago, Ill.
GEOPHYSICS	G. H. WESTBY, Seismograph Service Corporation, Tulsa, Okla.
APPALACHIANS	
North	JOHN R. REEVES, Penn-York Natural Gas Corporation, Buffalo, N.Y.
South	WILLIAM O. ZIEBOLD, 1572 Virginia Street, Charleston, W. Va.
NORTH CENTRAL STATES	R. B. NEWCOMBE, 303 South Main Street, Mount Pleasant, Mich.
KANSAS	ANTHONY FOLGER, Gulf Oil Corporation, Wichita, Kan.
OKLAHOMA	
Western	ROBERT H. DOTT, Oklahoma Geological Survey, Norman, Okla.
Eastern	SHERWOOD BUCKSTAFF, Shell Petroleum Corporation, Box 1191. Tulsa, Okla.
TEXAS	
North and Central	J. B. LOVEJOY, Gulf Oil Corporation, Fort Worth, Tex.
Northeastern	E. A. WENDLANDT, Humble Oil and Refining Company, Tyler, Tex.
Panhandle	JOHN E. GALLEY, Shell Petroleum Corporation, Amarillo, Tex.
San Antonio	HERSCHEL H. COOPER, 1015 Milam Building, San Antonio, Tex.
Permian Basin	HAL P. BYBEE, University Station, Box 2101, Austin, Tex.
GULF COAST	SIDNEY A. JUDSON, Texas Gulf Producing Company, Houston, Tex
	MARCUS A. HANNA, Gulf Oil Corporation, Houston, Tex.
ARKANSAS AND NORTH LOUISIANA	C. L. MOODY, Ohio Oil Company, Shreveport, La.
ROCKY MOUNTAINS	A. E. BRAINERD, Continental Oil Company, Denver, Colo.
CALIFORNIA	W. S. W. KEW, Standard Oil Company, Los Angeles, Calif.
	W. D. KLEINPELL, Box 1131, Bakersfield, Calif.
FOREIGN	
General	MARGARET C. COBB, Room 2703, 120 Broadway, New York, N. Y.
Europe	W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT, Staatstoezicht op de Mijnen, Heerlen, Holland
Canada	THEODORE A. LINK, Imperial Oil, Ltd., Calgary, Alberta
South America	HOLLIS D. HEDBERG, Mene Grande Oil Co., Apt. 35, Ciudad Bolivar, Venezuela

THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS is published by the Association on the 15th of each month. Editorial and publication office, 608 Wright Building, Tulsa, Oklahoma. Post Office Box 979. Cable address, AAPGEOL.

THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers, $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

German agent: Max Weg, Inselstrasse 20, Leipzig CI, Germany.

CLAIMS FOR NON-RECEIPT of preceding numbers of THE BULLETIN must be sent Association headquarters within three months of the date of publication in order to be filled gratis.

BACK NUMBERS OF THE BULLETIN, as available, can be ordered from Association headquarters. Paper-bound Vol. 2 (1918), $4.00; Vol. 3 (1919), $5.00. Cloth-bound Vol. 5 (1921), $12.00; Vols. 11 (1927) to 16 (1932), Vols. 18 (1934) to 21 (1937), each $17.00. Other volumes, many separate numbers, and a few nearly complete sets are available. Descriptive price list sent on request. Special prices to members and associates. Discounts to libraries. *Structure of Typical American Oil Fields*, Vol. II (1929), $7.00 ($5.00 to members and associates). *Stratigraphy of Plains of Southern Alberta* (1931), $1.50. *Geology of Natural Gas* (1935), $6.00 ($4.50 to members and associates). *Geology of Tampico Region, Mexico* (1936), $4.50 ($3.50 to members and associates). *Structural Evolution of Southern California* (1936), $2.00. *Gulf Coast Oil Fields* (1936), $4.00 ($3.00 to members and associates). *Comprehensive Index, 1917–1936* (1937), $3.00 (to members and associates: free; extra copy, $2.00).

THE BULLETIN furnishes thirty-five reprints of major papers. Additional reprints and covers for all or part are furnished at cost. ORDERS FOR REPRINTS should accompany corrected galley proof.

Association Headquarters—608 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

BOX 979

TULSA, OKLAHOMA

Entered as second-class matter at the Post Office of Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

(Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.)

OFFICERS FOR THE YEAR ENDING MARCH, 1939

DONALD C. BARTON *President*, Houston, Texas
HAROLD W. HOOTS, *Vice-President*, Glendale, California
IRA H. CRAM, *Secretary-Treasurer*, Tulsa, Oklahoma
WALTER A. VER WIEBE, *Editor*, Wichita, Kansas
(The foregoing officers, together with the *Past-President*, H. B. FUQUA, Fort Worth, Texas, constitute the Executive Committee.)

DISTRICT REPRESENTATIVES

(Representatives terms expire immediately after annual meetings of the years shown in parentheses)

Amarillo: Carl C. Anderson (40), Amarillo, Tex.
Appalachian: Robert W. Clark (39), Pittsburgh, Pa.
Canada: S. E. Slipper (39), Calgary, Canada
Capital: Arthur A. Baker (40), Washington, D. C.
Dallas: P. W. McFarland (40), Dallas, Tex.
East Oklahoma: Frederic A. Bush (39), R. B. Rutledge (39), W. B. Wilson (40), Tulsa, Okla.
Fort Worth: J. F. Hosterman (39), Tulsa, Okla.
Great Lakes: Benjamin F. Hake (39), Saginaw, Mich.
Houston: Orval L. Brace (39), David Perry Olcott (39), Wallace C. Thompson (40), Houston, Tex.
Mexico: William A. Baker (39), Brownsville, Tex.
New Mexico: Harold S. Cave (39), Roswell, N. Mex.
New York: W. T. Thom, Jr. (39), Princeton, N.J.
Pacific Coast: A. Arthur Curtice (39), Homer J. Steiny (39), E. J. Bartosh (40), Los Angeles, Calif.
Rocky Mountains: J. Harlan Johnson (39), Golden, Colo.
Shreveport: A. F. Crider (39), Shreveport, La.
South America: James A. Tong (39), Caracas, Venezuela
So. Permian Basin: Cary P. Butcher (39), Midland, Tex.
South Texas: Fred P. Shayes (39), Beeville; R. F. Schoolfield (39), San Antonio, Tex.
Tyler: A. C. Wright (39), Tyler, Tex.
West Oklahoma: V. G. Hill (39), Shawnee, Okla.
Wichita: Edward A. Koester (39), Wichita, Kan.
Wichita Falls: Virgil Pettigrew (40), Wichita Falls, Tex.

DIVISION REPRESENTATIVES

Paleontology and Mineralogy

E. H. Sellards (39), Austin, Tex.
Henry V. Howe (39), Baton Rouge, La.

PACIFIC SECTION (Chartered, March, 1925)

W. S. W. KEW, *President*, Standard Oil Company, Los Angeles, California
E. WAYNE GALLIHER, *Secretary-Treasurer*, 930 Petroleum Securities Building, Los Angeles, California

Membership restricted to members of the Association in good standing, residing in Pacific Coast states. Dues: $1.50 per year.

SOUTH TEXAS SECTION (Chartered, April, 1929)

W. A. MALEY, *President*, Humble Oil and Refining Company, Corpus Christi, Texas
C. C MILLER, *Secretary-Treasurer*, The Texas Company, Corpus Christi, Texas

Membership limited to persons eligible to Association membership. Dues: $2.50. Annual meeting in October.

MARACAIBO SECTION (Chartered, April, 1930)

JOHN L. KALB, *President*, Lago Petroleum Corporation, Maracaibo, Venezuela
CHESTER A. BAIRD, *Secretary-Treasurer*, Mene Grande Oil Company, Maracaibo, Venezuela

DIVISION OF PALEONTOLOGY AND MINERALOGY
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Organized, March, 1927; affiliated, March, 1928; chartered, technical division, April, 1930)

E. H. SELLARDS, *President*, Austin, Texas
HENRY V. HOWE, *Secretary-Treasurer*, Louisiana State University, Baton Rouge, Louisiana
SEND DUES, SUBSCRIPTIONS, AND ORDERS FOR BACK NUMBERS TO BOX 979, TULSA, OKLAHOMA.

The Society and the Paleontological Society jointly issue six times a year the *Journal of Paleontology*, Raymond C. Moore, University of Kansas, Lawrence, Kansas, and C. Wythe Cooke, U. S. Geological Survey, Washington, D. C., editors: subscription, $6.00. The *Journal of Sedimentary Petrology*, W. H. Twenhofel, editor, University of Wisconsin, Madison Wisconsin, is issued three times a year: subscription, $3.00. Single copies, *Journal of Paleontology*, $2.00; *Journal of Sedimentary Petrology*, $1.50. Society dues: with *Jour. Pal.*, $6.00; with *Jour. Sed. Petrology*, $3.00; with both, $8.00 per year.

AFFILIATED SOCIETIES

(Dates of affiliation in parentheses)

Alberta Society of Petroleum Geologists, Calgary, Alberta, Can. (31). S. E. Slipper, Secy., 215 Sixth Avenue, West
Appalachian Geological Society, Charleston, W. Virginia (31). Charles Brewer, Jr., Secy., Godfrey L. Cabot, Inc., Box 348
Ardmore Geological Society, Ardmore, Oklahoma (36). J. P. Gill, Secy., Sinclair Prairie Oil Company
Dallas Petroleum Geologists, Dallas, Texas (35). W. W. Clawson, Secy., Magnolia Petroleum Company
East Texas Geological Society, Tyler, Texas (32). C. L. Herold, Secy., Shell Petroleum Corporation
Fort Worth Geological Society, Fort Worth, Texas (31). Herbert H. Bradfield, Secy., The Texas Company
Houston Geological Society, Houston, Texas (32). Lon D. Cartwright, Jr., Secy., Skelly Oil Company
Kansas Geological Society, Wichita, Kansas (31). Forrest E. Wimbish, Secy., 517 North Chautauqua
Michigan Geological Society, Mount Pleasant, Mich. (37). W. A. Clark, Secy., Box 29
North Texas Geological Society, Wichita Falls, Texas (38). Paul E. M. Purcell, Secy., Shell Petroleum Corporation
Oklahoma City Geological Society, Oklahoma City, Oklahoma (31). R. B. Curry, Secy., Carter Oil Company
Panhandle Geological Society, Amarillo, Texas (32). G. R. Carter Secy., Gulf Oil Corporation
Shawnee Geological Society, Shawnee, Oklahoma (31). J. Lawrence Muir, Secy., Amerada Petroleum Corporation
Shreveport Geological Society, Shreveport, Louisiana (32). J. D. Aimer, Secy., Arkansas-Louisiana Gas Company
Society of Exploration Geophysicists, Houston, Tex. (32). H. B. Peacock, Secy., 825 Esperson Building
South Louisiana Geological Society, Lake Charles, La. (37). W. R. Canada, Secy., 207 Weber Building
Southwestern Geological Society, Austin, Texas (37). Robert C. Redfield, Secy., Geological Department, University of Texas
Tulsa Geological Society, Tulsa, Oklahoma (31). L. A. Johnston, Secy., Sunray Oil Company
Western Kentucky Geological Society, Owensboro, Kentucky (38). R. E. Knipe, Secy., The Ohio Oil Company
West Texas Geological Society, Midland, Texas (38). W. C. Fritz, Secy., Skelly Oil Company

Haloid RECORD

Withstands Extremes of Heat and Humidity with Dependable Uniformity

GRUELLING summer field and laboratory conditions under which geophysical recordings are made, are a real test of the qualities of a recording paper.

Results show that Haloid Record withstands the extremes of heat and humidity with consistent performance. Haloid Record develops fast and is easy to manipulate. Contrast is exceptionally sharp . . . whites are snowy white and blacks are dense black. Wide latitude in exposure and development lessens waste. Recordings are dependably uniform regardless of heat or humidity. Sheen and curl are reduced to a minimum.

Now is the time to use Haloid Record. Sample rolls for test purposes sent gladly on request. (Write Dept. 61)

THE HALOID COMPANY, ROCHESTER, N. Y.

Successful Sensitizers for 32 Years

POLAR CORE ORIENTATION

(U. S. Patents 1,778,981: 1,792,639: 2,089,216: 2,104,752: 2,105,650 and others pending)

The orientation of a core to determine its direction of dip is performed in our Laboratory, to which selected core samples, taken by any type core barrel in the ordinary course of drilling, are shipped from any distance. No special equipment is required at the well, nor is the program of drilling impeded.

The cores received at our Laboratory are first ground into true cylinders and afterwards tested in our automatically operated orientation apparatus, which photographically records the polarity of the core, from which the magnetic North-South axis is located. The results of this method are accurate and reliable. The value of knowing the direction of dip in wildcat wells, or in unexplored deeper zones or defining structures in proven fields is well known.

SELECTION AND PREPARATION

1. Type and Size of Samples—Samples with *visible indications of a bedding plane* should be taken from the core barrel by the geologist as soon as the core barrel is returned to the surface and should be marked at that time indicating "Top" and "Bottom."

Core samples of soft formation, or those which easily disintegrate, should be carefully washed of all drilling mud and all other foreign substances. The clean core should then be dipped in Sherwin-Williams clear lacquer of vegetable compound and then wrapped tightly in "Kodapak" with the ends also protected.

Materials which contain heavy mineral grains, distributed throughout, such as sandstones, sandy shales or shales streaked with sand are the most suitable. Pure limestone, dolomite or anhydrite are not workable.

Cores without visible stratification other than breaks along the bedding planes can be used if notation indicating these breaks represent the true bedding is made by the geologist on the envelope containing the core sample.

The samples received should not be less than two (2) inches in diameter and the lengths between perpendicular ends should not be less than three (3) inches. Samples of smaller size, if smooth and unbroken, will be tested at customer's risk.

2. Number and Depth Range—One set of cores or samples shall comprise not less than three (3) and not more than five (5) individual cores or samples taken within a depth range of *not more than one hundred feet (100') in one bore hole.*

3. Precautions in Handling—Cores prepared for orientation should be carefully packed so as to avoid breakage in transit. They should never be left in the vicinity of any direct or alternating current field, or near any magnetic field.

4. Data Required—Samples should be accompanied by a letter giving the following information:

a. Identification of set of samples by well, name, and number and its approximate location by Field, County and State. If desired the well can be identified by a code number.
b. Type of material of samples.
c. Geological horizon of samples.
d. Depth from which each sample was taken.
e. Inclination and direction of the hole at depth at which samples were taken. *This is extremely important* when submitting samples with very low angle bedding planes.
f. Magnetic declination of locality where samples were taken.

METHOD OF SERVICE

Forward samples and information to our Laboratory at 549 East Bixby Road, Long Beach, California, carefully packed to avoid breakage. A comprehensive report on the findings will be dispatched within three days of receipt, or earlier if possible. The service is strictly confidential.

SERVICE CHARGES

Service charges depend upon the results obtained and are as follows:

a. Determining the orientation from a set of three (3) to five (5) samples $150.00
b. Service charge for running three (3) to five (5) samples through apparatus when samples fail to show polarization $100.00
c. Service charge for three (3) to five (5) samples which after grinding fail to show bedding planes ..... $ 50.00

Remittance covering charge for orientation must accompany core samples shipped from foreign countries.

SPERRY-SUN WELL SURVEYING COMPANY

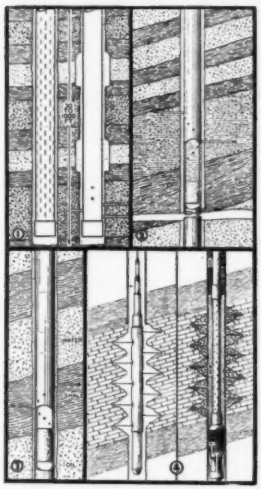
1608 WALNUT STREET, PHILADELPHIA, PA.

HOUSTON, TEXAS	CORPUS CHRISTI, TEXAS	LAFAYETTE, LA.	TULSA, OKLAHOMA
3118 Blodgett Ave.	332 N. Morningside Drive	Bonnet Building Cor. Lafayette & W. Vermillion Sts.	425 Petroleum Bldg.

LONG BEACH, CALIF.	SANTA BARBARA, CALIF.	BAKERSFIELD, CALIF.
549 E. Bixby Road (3800 Block—Atlantic Ave.)	1409 E. Valley Road	17th & "I" Sts. (Elks Club)

These Men Give You STRAIGHT FACTS On *Gun Perforating* Oil Wells

4 advantageous uses for STRAIGHT safe, accurate gun perforating



1. Cement Blank Liners In Wells—Set your casing and cement it solid throughout the entire productive horizon. Then gun perforate and produce possible zones starting at bottom and working up.

2. Before Abandoning Wells—Before abandoning a well test all probable producing zones. Engineering records are usually available showing these zones and inexpensive gun testing programs justified.

3. For Efficient Cement "Squeeze" Jobs—For efficient cement "Squeeze" jobs, on either water or gas conditions gun perforate. Perforating makes effective and positive shots.

4. To Make Better Channels for Acid Treatment—In perforating for acid treatment holes can be placed in the saturated zone for maximum efficiency and economy.

Tomorrow's Tools Today

If you want to get the "real low-down" on gun perforating, talk to the superintendents, the engineers and the men on the rig. They'll tell you what they expect of a gun perforator and why Lane-Wells equipment and service is universally preferred. They'll tell you that trained "gun crews" follow directions in every detail, that they shoot the job according to the operator's specifications, that they get on the rig and off the rig with the minimum amount of shut-down time. They'll tell you further that not only the Lane-Wells Gun Perforator itself, but the loads, conductor-core cable, electrical control devices, trucks,—in fact all service equipment,—are constructed and maintained with the highest degree of engineering skill. They'll remind you that Lane-Wells equipment and personnel will be where you want them, when you want them ready to do the job as you want it done with but one thought in mind—the maximum results for the operator in minimum time.

LANE WELLS COMPANY

GENERAL OFFICES AND PLANT
5610 S. Soto St. Los Angeles, Calif.

EXPORT OFFICES
420 Lexington Ave., New York City, N. Y.

DIVISION HEADQUARTERS
PACIFIC COAST—Los Angeles, California • GULF COAST—Houston, Texas
MID-CONTINENT—Oklahoma City, Oklahoma

FIELD BRANCHES
TEXAS—Corpus Christi, Longview, Odessa, Victoria • LOUISIANA—Lake Charles, Shreveport
OKLAHOMA—Tulsa, Seminole • CALIFORNIA—Bakersfield, Long Beach, Santa Barbara
KANSAS—Hutchinson • WYOMING—Casper

FOURTH BAY OILER FLOWS 400 BARRELS

Gives New Tidal Field a Perfect Record of No Failures; New Location Also Staked.

Completion of another and the fourth Galveston Bay well, and staking of a new location was reported Friday by the Standard Oil Company of Texas-Salt Dome Oil Corporation joint interests in the new Cedar Point field. The new producer, No. 1 119 State, ... was cleaning, ... showing ... and

★

FOUR PRODUCERS

No failures

Completion of the fourth Galveston Bay well gives this area a record of four producers without a single failure.

The difficult job of locating the prospect for these wells in the bay was intrusted to the Askania Torsion Balance.

How well Askania equipment did its job is attested by the perfect record of four wells—no failures.

Askania equipment can help you with your difficult prospecting problems. A request will bring you complete information.

AMERICAN ASKANIA CORPORATION

M & M BUILDING **HOUSTON, TEXAS**

ASKANIA

Bulletin Advertisers

American Askania Corporation vi
Amer. Inst. Min. Met. Eng. .....
American Paulin System .....
Baker Oil Tools, Inc. ..... Inside front cover
Baroid Sales Department xxiv
William M. Barret, Inc. xviii
Bausch and Lomb xxi
Borntraeger Brothers xxii
Dowell Incorporated viii
Eastman Kodak Stores, Inc. xxiv
Eastman Oil Well Survey Company xxvii
Economic Geology Publishing Company ... xvii
George E. Failing Supply Company .....
First Natl. Bank and Trust Co. of Tulsa xxii
Geological Scientific Service Company ... xxvi
Geophysical Service, Inc. .... Inside back cover
Geotechnical Corporation xxii
Gulf Publishing Company xx
Haloid Company iii
Hughes Tool Company .... Outside back cover
Illinois Powder Manufacturing Company .. xvii
Independent Exploration Company xix
International Geophysics, Inc. xxv
Journal of Geology xvii
Journal of Paleontology xxviii
Journal of Sedimentary Petrology xxviii
Lane-Wells Company v
E. Leitz, Inc. .....
Reed Roller Bit Company .....
Revue de Géologie xvii
Schlumberger Well Surveying Corporation ....
Seismic Explorations, Inc. .....
Seismograph Service Corporation xxiii
Spencer Lens .....
Sperry-Sun Well Surveying Company iv
Sullivan Machinery Company .....
Triangle Blue Print and Supply Company .. xvii
Verlag für Fachliteratur xxiv

PROFESSIONAL CARDS

Joseph L. Adler xii
William M. Barret x
Donald C. Barton xii
Elfred Beck xi
Brokaw, Dixon & McKee ... xi
D'Arcy M. Cashin xii
Frederick G. Clapp xi
Willard J. Classen ix
Richard R. Crandall ix
Ronald K. DeFord x
E. DeGolyer xii
Alexander Deussen xii
David Donoghue xii
R. B. Downing x
Robert H. Durward xiii
J. E. Eaton ix
R. H. Fash xii
A. H. Garner xi
R. L. Ginter xi
Paul P. Goudkoff ix
C. A. Heiland x
Malvin G. Hoffman xi
Holl and Oborne x
Hudnall & Pirtle xiii
Huntley & Huntley xii
John S. Ivy xiii
W. P. Jenny xiii
Vernon L. King ix
H. Klaus ..... xi, xii
E. W. Krampert xiii
R. W. Laughlin xi
U. R. Laves xii
Marvin Lee x
A. I. Levorsen xi
George C. Matson xii
Phillip Maverick xiii
C. R. McCollom ix
Wm. C. McGlothlin xiii
Chas. Gill Morgan x
L. C. Morgan x
R. H. Palmer x
Dabney E. Petty xiii
John L. Rich xi
E. E. Rosaire xiii
W. G. Saville xiii
J. P. Schumacher xiii
A. T. Schwennesen xiii
R. W. Sherman ix
Jack M. Sickler ix
J. Y. Snyder x
Walter Stalder ix
Irvine E. Stewart ix
R. L. Triplett x
Harold Vance xiii
G. H. Westby xii
John H. Wilson x

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

Appalachian xvi
Ardmore xiv
Dallas xv
East Texas xv
Exploration Geophysicists .xvi
Fort Worth xv
Houston xv
Kansas xiv
North Texas xvi
Oklahoma City xiv
Rocky Mountain xiv
Shawnee xv
Shreveport xiv
South Louisiana xiv
South Texas xvi
Stratigraphic xv
Tulsa xv
West Texas xvi

Articles for August *Bulletin*

South Arkansas Stratigraphy with Emphasis on the Older Coastal Plain Beds
By WARREN WEEKS

Subsurface Tertiary Zones of Correlation through Mississippi, Alabama, and Florida
By DONALD W. GRAVELL and MARCUS A. HANNA

Comparison of Permian Ammonoid Zones of Soviet Russia with Those of North America
By A. K. MILLER

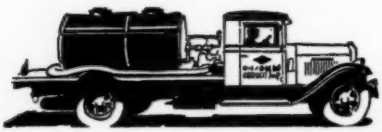
Petroleum and Natural Gas in Non-Marine Sediments of Powder Wash Field in Northwestern Colorado
By W. T. NIGHTINGALE

Wilmington Oil Field, Los Angeles County, California
By E. J. BARTOSH

Rôle of Petroleum Geologist in Development of the Law of Oil and Gas
By GEORGE A. WILSON

Early Development of Drilling Practices in Kanawha County, West Virginia
By J. E. BILLINGSLEY

Anticlinal Theory and Later Developments in West Virginia
By PAUL H. PRICE



Out in Front . . . with *Inhibited* Acidizing

Right now, thousands of oil producers are congratulating themselves on their decision to take no chances with "raw" acid but to let Dowell do the job right with Dowell *Inhibited* Acid.

Raw acid dissolves limestone—but not any faster or better than Dowell *Inhibited* Acid.

But, raw acid also dissolves iron—it eats away on tubing, casing and equipment. Long after the treatment is over its destructive action is at work piling up a ruinous bill of damage.

Halting corrosive action of hydrochloric acid on metal through the addition of an "inhibitor" was Dowell's first great contribution to chemical well treating. It is, fundamentally, what has put Dowell "out in front" with thousands of operators who are unwilling to gamble, and lose.

Stay "out in front" with Dowell—a service based on scientific treating with sound, effective materials.

NEW! DOWELL "XR" ACID The Sustained Action Acid

Dowell's latest achievement—a new principle of acid action. Dowell "XR" Acid is kept live till it travels far into the pay zone. Get the facts on Dowell "XR." Information at all Dowell stations.

DOWELL INCORPORATED

Subsidiary of THE DOW CHEMICAL COMPANY

General Office: Kennedy Bldg., Tulsa, Okla.

Now in MEXICO . . . DOWELL SOCIEDAD ANONIMA, San Juan de Letran No. 6, Desp. 101
Apartado Postal 24-24, Mexico, D.F., Mexico
Esquina: 2a. 63a. Avenidas. La Isleta, Apartado Postal 438, Tampico, Tamaulipas, Mexico

DISTRICT OFFICES

Ada, Oklahoma
Amarillo, Texas
Borger, Texas
Calgary, Alberta
Cody, Wyoming
Eureka, Kansas
Flora, Illinois
Great Bend, Kansas
Hays, Kansas
Hobbs, New Mexico
Lawrenceville, Illinois
Long Beach, California
McCamey, Texas
Midland, Texas
Mt. Pleasant, Michigan
Newton, Kansas
Okotoks, Alberta
Seagraves, Texas
Seguin, Texas
Seminole, Oklahoma
Shelby, Montana
Shreveport, Louisiana
Stamford, Texas
Stonewall, Oklahoma
Tulsa, Oklahoma
Wichita, Kansas

DOWELL

OIL AND GAS WELL CHEMICAL SERVICE

Volume 22 Number 7

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

JULY, 1938

STRATIGRAPHY OF COASTAL PLAIN OF GEORGIA[1]

C. WYTHE COOKE[2] AND ARTHUR C. MUNYAN[3]
Washington, D. C., and Atlanta, Georgia

ABSTRACT

The senior writer has recently completed a revision of the stratigraphy of the Coastal Plain of Georgia, which it is expected will form part of a report on the geology of the state to be published by the Department of Natural Resources of Georgia. The map accompanying it shows the outcrop of formations ranging in age from Upper Cretaceous (Tuscaloosa) to Recent. The overlap of successively younger formations toward the east is conspicuous. The major structural features to be inferred from the distribution of formations are a broad shallow basin centering off the southern part of the coast and a flattening of the strata (probably without reversal of dip) in the western part of the state.

The basement rocks beneath the Coastal Plain of Georgia are believed to consist entirely of igneous and metamorphic rocks, chiefly granites, gneisses, and schists, resembling those of the Piedmont region, which they adjoin and of which they are believed to be the continuation. Little is known about them except along the border of the Piedmont, where they are exposed in many valleys and have been penetrated by many wells in the adjoining uplands. This basement appears to be part of the deeply eroded land surface of an ancient continent which probably extended eastward to the edge of the continental shelf.

The distribution of the more important of the surficial formations is shown in the map (Fig. 1) which is much generalized from a geologic map by the senior writer, and which it is expected will be published on a scale of 1/500,000 by the Division of Mines, Mining, and Geology of Georgia.

[1] Read before the Association at New Orleans, March 16, 1938, and published with the permission of the directors of the Geological Survey and the Division of Mines, Mining, and Geology of Georgia. Manuscript received, February 3, 1938.

[2] Geological Survey.

[3] Assistant State geologist of Georgia.

No representative of the Comanche series has been discovered in Georgia. The oldest known deposit on the crystalline basement is the Tuscaloosa formation, which is classified as early Upper Cretaceous because of its fossil leaves, which correlate it with the Woodbine sand of Texas. No marine fossils have been found in the Tuscaloosa formation in Georgia. It consists chiefly of coarse drab sand with intercalated lenses of white and purple clay. The outcrop of the Tuscaloosa

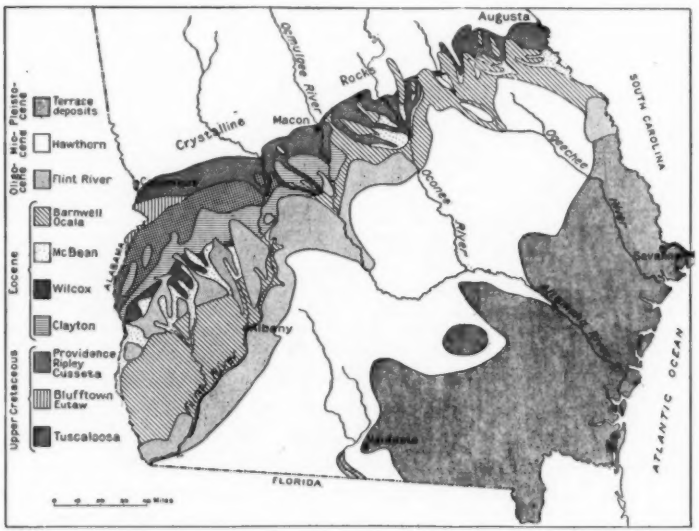


FIG. 1.—Generalized geologic map of Coastal Plain of Georgia by C. Wythe Cooke, 1938.

extends as a wide belt from Chattahoochee River to Savannah River, but east of the Ocmulgee its continuity is broken at several places by an overlap of the Upper Eocene Barnwell formation.

The Upper Cretaceous series above the Tuscaloosa is divisible into five formations, which are exposed only west of Flint River. The marine Eutaw formation, which lies unconformably on the Tuscaloosa, is overlain on Chattahoochee River by sands and clays that form the basal part of the Blufftown formation as here interpreted, but which were not included in Otto Veatch's original (1909) definition of the Blufftown marl.

The Blufftown is overlain unconformably by the Cusseta sand, which overlaps it and the Eutaw in Marion County and extends east-

ward on the Tuscaloosa as far as Peach County, where it is overlain by the basal Eocene Clayton formation.

Above the Cusseta lies more than 100 feet of dark gray micaceous sand representing the Ripley formation, which includes the middle and lower parts of the *Exogyra costata* zone and contains an abundance of other marine shells. A more restricted zone (*Exogyra cancellata* zone) is included in the lower part of the *E. costata* zone. The Ripley has not been recognized with certainty east of Ideal, Macon County. A greater thickness of the Ripley is exposed along the Chattahoochee than farther east.

The Providence sand lies unconformably on the Ripley and extends from Chattahoochee River to Flint River, beyond which it is overlapped by the Clayton formation. The lower course of Pataula Creek, a tributary of Chattahoochee River, is cut in gray fossiliferous sand alternating with ledges of coarse-grained sandstone, which seems to be an off-shore facies of the Providence sand. The Providence is the youngest Cretaceous formation exposed in Georgia.

The basal Eocene Clayton formation, of Midway age, lies unconformably on the Providence west of Flint River. East of the Flint the Clayton overlaps across the younger Upper Cretaceous deposits to the Tuscaloosa formation, on which it lies as far east as Twiggs County. East of Twiggs County the Clayton is overlapped by the Barnwell formation and by the McBean formation. The typical facies of the Clayton is white sandy limestone, but in Georgia there is also much clayey sand, which weathers bright red. This firm red sand upholds a northwestward-facing escarpment overlooking the more easily eroded Cretaceous hills.

The next younger Eocene deposit is the Wilcox formation, which is not subdivided in Georgia and is exposed only in the valleys of western Georgia. It is completely overlapped by the McBean formation east of Muckalee Creek.

The McBean formation, which apparently represents the Tallahatta formation and the Lisbon formation of Alabama, extends completely across Georgia but it is overlapped by the Ocala limestone along Ocmulgee River. The Flint River formation overlaps it in the west and the Barnwell formation overlaps it in the east, but valleys cut through these two formations reach the McBean. A thin fossiliferous marl bed at the base of the McBean may prove to be a useful horizon marker for subsurface correlation.

The Ocala limestone, extensively developed in the southwest, and the Barnwell formation, in the northeast, meet and merge in Twiggs County. Both lie unconformably on the McBean formation and over-

lap it. Both are of Jackson age. The Barnwell represents a littoral facies of the Ocala. There are outliers of the Ocala on the Tuscaloosa at Rich Hill, Crawford County, and the Barnwell extends even to the crystalline rocks of the Piedmont. The Cooper marl, which contains Upper Eocene *Foraminifera*, overlies the Barnwell near Millen and overlies the Ocala at Clinchfield. Only a few outcrops have been recognized. The Cooper has not heretofore been recognized in Georgia.

No early Oligocene deposits are known in Georgia. The Flint River formation, formerly supposed to be a facies of the Glendon limestone, has been proved somewhat younger. It is tentatively correlated with the Chickasawhay member of the Byram marl of Mississippi. The Flint River formation overlaps the Eocene formations as far as the Clayton. East of Oconee River it is overlapped by the Hawthorn formation but reappears in the Savannah drainage basin. The Suwannee limestone, which apparently is of about the same age as the Flint River formation, projects a few miles up the valley of Withlacoochee River north of the Florida-Georgia line.

The Tampa limestone, of basal Miocene age, extends northward from Florida a few miles up the valleys of the Ochlockonee and the Flint. A narrow band of Tampa has been traced by means of residual chert along the foot of the Tifton Upland as far north as Sylvester. The Tampa is overlain by the Hawthorn formation, which occupies a band 80 miles wide trending northeastwardly across the state. There are few recognizable horizon markers in this enormous area. The Hawthorn consists mostly of lenses of sand and gravel but includes some marine marl beds and extensive deposits of fuller's earth. It overlaps the Tampa and Flint River formations onto the Barnwell.

The next younger formation is the Duplin marl, of Upper Miocene age. The Duplin is known to crop out only in bluffs along Savannah River at and near Porters Landing and at Doctortown on the Altamaha.

The marine Pliocene (?) is represented in Georgia only by approximately 20 feet of light-colored clay and impure limestone, the Charlton formation, which is exposed along St. Marys River and near the Satilla.

A broad belt adjoining the ocean is underlain by marine sand of Pleistocene age deposited by seven repeated invasions of the sea. Remnants of the deposits of the earliest invasion (the Brandywine formation) have been recognized nearly 100 miles from the present coast at altitudes approximating 270 feet above sea-level. Progressively younger and lower deposits are called the Coharie, Sunderland, Wicomico, Penholoway, Talbot, and Pamlico formations. Bones of

mastodons and giant ground sloths have been found above the shell bed in the Pamlico near Savannah and Brunswick.

The sea islands, chiefly of Pamlico age, and the tidal marshes, of Recent origin, form a band 10 or 12 miles wide along the coast. The marshes extend 20 miles or more up all the estuaries.

A significant feature brought out by study of the geologic map is the much more complete outcrop of the formations in the west than elsewhere. Near Chattahoochee River eleven formations are exposed between the Tuscaloosa and the Hawthorn formations. Near the Ocmulgee there are only four, and along the Savannah there are only three. This difference is not the result of lithologic simplification, but of progressive overlap. It appears to indicate either an intermittent downwarp in the central and eastern parts of the state, which permitted the ocean to advance farther and farther inland, or an uplift in the west, which hastened the erosion of the littoral facies of the younger formations and exposed more and more of the underlying beds.

That there has been some post-Oligocene downwarp in the southeast is shown by Prettyman and Cave's structure map,[4] which, although based on inadequate and perhaps to some extent unreliable data, probably outlines correctly the major structural features of the southeastern part of Georgia. That there may have been also slight uplift or at least flattening of the strata in the Chattahoochee region in line with the Ocala arch of Florida but separated from it by a structural "low" is suggested by the great width of the outcrop of the Ocala limestone in southwestern Georgia and by the considerable body of younger deposits between the two areas of Ocala outcrop.

[4] T. M. Prettyman and H. S. Cave, "Petroleum and Natural Gas Possibilities in Georgia," *Georgia Geol. Survey Bull. 40* (1923), map facing p. 134.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 794-798

RECENT PETROLEUM ACTIVITIES IN COASTAL PLAIN OF SOUTH GEORGIA[1]

A. C. MUNYAN[2]
Atlanta, Georgia

ABSTRACT

A brief discussion of the structural map prepared by Prettyman and Cave in 1923 is presented to show that their key bed was unwisely selected. Many wells drilled in the past are practically useless for correlation purposes to-day because of the lack of suitable records. In addition there are few aids to correlations outside of lithology, and it is suggested that a comprehensive study of the microfauna be made. Several comparisons are made to show the possible relation between topography and subsurface structure in three widely separated parts of the Georgia Coastal Plain, and hope is expressed that these areas will be investigated. News of leasing and future deep tests is brought up to date as far as possible.

The structural deformations of the rocks of the Georgia Coastal Plain have been studied at various times by different individuals, most of them deciding that the possibilities of finding either oil or gas were slight. Prettyman and Cave[3] prepared a structural map of the region which shows the presence of several broad warpings in the southeastern part of the Coastal Plain area. This map, however, was based on the use of the greenish clay at the base of the formation which was then called the Alum Bluff formation, and is now known as the Hawthorn. As Cooke has shown in the paper, "Stratigraphy of the Coastal Plain of Georgia," the Hawthorn is a formation overlapping onto successively older ones, and as such does not reflect the true attitude of the older beds. Any structure so indicated would necessarily have been formed during or after Miocene time.

A geologic map of the Coastal Plain shows that a great area is blanketed by the Hawthorn, effectively concealing the underlying formations to such a degree that to map the surface geology is virtually a physical impossibility. Therefore, without the use of geophysical instruments, few data can be obtained on subsurface conditions. Attempts have been made to assemble and correlate the logs of water wells from the area, but so far nothing of importance has been accomplished. Similarly, many wildcat wells have been drilled in prospecting for petroleum, but their logs have not furnished adequate information for correlative purposes. Several of the more

[1] Read by title before the Association at New Orleans, March 18, 1938. Manuscript received, February 3, 1938.

[2] Assistant State geologist.

[3] T. M. Prettyman and H. S. Cave, "Petroleum and Natural Gas Possibilities in Georgia," *Georgia Geol. Survey Bull. 40* (1923), opposite p. 134.

important logs are given at the end of this paper for reference purposes.

One of the most interesting prospect wells drilled in the state is that of the Dixie Oil Company which was located near McRae in Telfair County. It is perhaps the deepest well drilled in the state in the search for oil and its record has been a matter for speculation since its abandonment. The total depth as recorded in the State offices is 3,384 feet, which would make the depth below sea-level approximately 3,250 feet. There are no records available to show whether there was any indication of either oil or gas in the hole, but it is highly probable that nothing of the sort was encountered. Many versions of the story giving reasons why this well was so suddenly abandoned are being circulated. One story is that oil was struck but that the company decided to shut it in for some unknown reason. Another tale is that the crystalline rocks were encountered. The last story is that the company decided that nothing could be gained by further drilling and, because of a need for the driller and crew elsewhere, ordered the well plugged very suddenly. The Division of Mines, Mining, and Geology is inclined to accept the last explanation in lieu of a better one, but no authentic information has been submitted either to disprove or prove the matter.

A glance at the log of the McRae well will show that little information can be obtained from it for correlation purposes. It is evident from the log that it is the driller's record of his interpretation of the formations which were penetrated, and as such is of little use to the geologist. To overcome this difficulty the State has recently inaugurated a program of saving well cuttings from all known drilling wells. It is hoped that careful examination of these samples will disclose some possible means of subsurface correlation. The cuttings are filed so that they can be located easily. However, any information that the Division of Mines obtains for this purpose will not be made public without the consent of the owner.

Some efforts[4] have been made to describe the microfauna of a few of the better known Coastal Plain formations, but there is not sufficient information along this line to make possible definite correlations at present. The prospective operator in Georgia will probably find it profitable to employ a competent micropaleontologist. The State at the present time is not prepared to render such service, but can arrange for it to be performed at the expense of the operator. It is in order to facilitate the foraminiferal studies that the sample file has been started, and it is hoped that all operators in Georgia will

[4] See papers by Cushman; also by Cooke.

coöperate with the State offices so that more will become known about the subsurface geology.

SURFACE GEOLOGY

The Hawthorn formation, as stated in the foregoing paragraphs, blankets the southeastern part of the Coastal Plain so effectively that little detailed mapping can be done. Nevertheless, there are some broad regional structural trends indicated. The most outstanding example of peculiar topographic expression which may be due to structure is the course of Altamaha River and its tributary, Ocmulgee River. The state geographic map shows that the Ocmulgee naturally would flow in a southeasterly direction, but that it has a reversal of course in southwestern Telfair County, to the northeast until it joints the Altamaha, which in turn curves back to the southeast once more. The writer believes that it is entirely possible for this alteration of course to be due to a broad doming of the underlying rocks. However, it must be stated that, lacking topographic map evidence, this peculiar feature might be the result of stream piracy, on the part of Altamaha River, of the head waters of Alapaha River toward which Ocmulgee River seems to flow prior to its abrupt change of course. Recent leasing activities south of Altamaha River appear to support the theory of possible structural influence on the river's course, for it is a matter of common knowledge that leases have been taken on the basis of detailed geophysical data.

Another area, which has been more or less ignored, and which may be worthy of attention, is the one located west of Flint River in Calhoun, Dougherty, and Baker counties. The Ocala limestone crops out over most of that area according to Cooke. Formerly it was considered to be Vicksburg by Stephenson and Veatch[5] who mapped the area in conjunction with a study of the underground waters of the Coastal Plain. Stephenson and Veatch compiled a map showing the areas of flowing and non-flowing water wells. In the counties under discussion, many flowing wells are found in a triangular area with one of the apices pointing south. Immediately west of the flowing-well region is one in which the water wells do not flow. Since both the flowing and non-flowing areas are in the Ocala limestone outcrop, it is reasonable to suppose that some unknown structure may be the cause of the anomaly.

Cooke[6] is of the opinion that this peculiarity can be explained by

[5] L. W. Stephenson and Otto Veatch, "Underground Waters of the Coastal Plain of Georgia," *U. S. Geol. Survey Water-Supply Paper 341* (1915).

[6] C. W. Cooke, personal communication, January, 1938.

differences in topography. However, if the elevations are compared in both areas, it will be found that, strangely enough, the region of flowing wells is generally higher than the area of non-flowing wells, while the reverse should be true if the difference is caused by topography. Consequently, it is the writer's belief that there probably is some other reason for this phenomenon. Perhaps there are undetected structures in the Ocala outcrop region which cause this effect. No work has been done in the region to prove the theory.

A third topographic feature in which much interest has been evinced by geologists is Trail Ridge, which extends from Florida north into Georgia just east of the Okefenokee Swamp. Cooke[7] has explained the presence of this ridge on the basis of a barrier beach or bar theory which seems to be very logical. However, there have been some suggestions from various geologists that perhaps the ridge is the result of some orogenic movement. In fact, one person has reported finding tilted and folded beds in an outcrop in the vicinity of Doctortown, located in Wayne County on Altamaha River. The writer has not visited the locality and can not personally vouch for the fact. Nevertheless, a detailed map of Trail Ridge would not be amiss in view of the interest in local subsurface geology.

RECENT OPERATIONS IN GEORGIA

There have been two geophysical parties in the state within the past year and a half mapping the subsurface structure in the southeastern parts of the Coastal Plain. What results they have obtained have not been made public, but it is known that a great many leases have been secured on the basis of favorable reports from the work. Other companies and individuals have entered the state because of rumors to this effect, and are taking leases in many counties. Most of the activity seems to center in the counties north and west of the Okefenokee Swamp, including Clinch, Ware, Pierce, Atkinson, Coffee, Jeff Davis, Bacon, Appling, Wayne, and Telfair counties.

Many of the major companies are now placing their representatives in strategic locations through this region to watch closely all developments. Several of these men are stationed at Waycross, Georgia, from which location most of the area is easily accessible.

Reports from good authorities indicate that exhaustive tests will be drilled at favorable points in the near future. It is hoped that the State Division of Mines, Mining, and Geology will secure cuttings from these wells for use in their proposed laboratory studies.

[7] Wythe Cooke, "The Coastal Plain," *in* Laurence La Forge, Wythe Cooke, Arthur Keith, and Marius Campbell, "Physical Geography of Georgia," *Georgia Geol. Survey Bull. 42* (1925), pp. 27–29.

Since the presentation of this paper before the New Orleans annual meeting of the American Association of Petroleum Geologists a test well has been drilled and completed in Landlot 329, Pierce County, Georgia, by the Pan-American Production Company. The well, drilled to a total depth of 4,375 feet, proved to be a dry hole after completion in granite. The company reports that there were no showings of gas or oil. Future drilling plans in the region have not yet been formulated.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 799-815, 1 FIG.

OIL AND GAS POSSIBILITIES IN ATLANTIC COASTAL PLAIN FROM NEW JERSEY TO FLORIDA[1]

OLIVE C. POSTLEY[2]
Washington, D. C.

ABSTRACT

On account of recent interest in oil possibilities in parts of the Atlantic Coastal Plain, especially southern Georgia and Florida, this paper gives a summary of the known general geologic features of states along the Atlantic Coast from New Jersey to Florida and of wells drilled in the region to depths of 1,000 feet or more. No oil in commercial amounts has been found in the Atlantic Coastal Plain, and the aggregate thickness of the Cretaceous and Tertiary sediments in most parts of it is not sufficient to encourage the hope that oil pools will be found; in fact, wells at several places have encountered basement rocks at shallow depths. In southeastern Georgia and southern Florida, however, where only a few deep wells have been drilled, the basement rocks lie at greater depth, and the deeply buried Cretaceous and Tertiary formations are little known. Further drilling will be required to determine their character and to test their oil possibilities.

INTRODUCTION

Interest has recently been manifested in the oil possibilities of parts of the Atlantic Coastal Plain, especially in southeastern Georgia and in Florida, and, according to reports, geophysical investigations are being conducted by some oil companies in those regions. This paper has therefore been prepared with a view to giving a short summarized account of known general geologic conditions and of deep wells that have been drilled in the Atlantic Coastal Plain from New Jersey to Florida. The greater number of wells in the region have been drilled for water and are relatively shallow, but there are numerous deeper wells, some of which have been drilled in search for oil.

The Atlantic Coastal Plain is clearly indicated east of the Piedmont Plateau on the geologic map of the United States published by the Geological Survey in 1933. The outlines of the Cretaceous, Tertiary, and younger formations, shown on that map, have been indicated on the accompanying sketch map (Fig. 1) which also shows locations, by numbers, of wells that are mentioned throughout the paper.

The deposits of the Coastal Plain represent sediments of different kinds, ranging in age from the Lower Cretaceous to the Recent. They lie in an unconformable sequence, but there is, in general, a marked uniformity of dips and strikes. The strata form thin wedges at the Fall Line but increase in thickness eastward toward the ocean. From

[1] Manuscript received, March 1, 1938. Read by title before the Association at New Orleans, March 18, 1938. Published by permission of the director of the United States Geological Survey.

[2] Assistant geologist, United States Geological Survey.

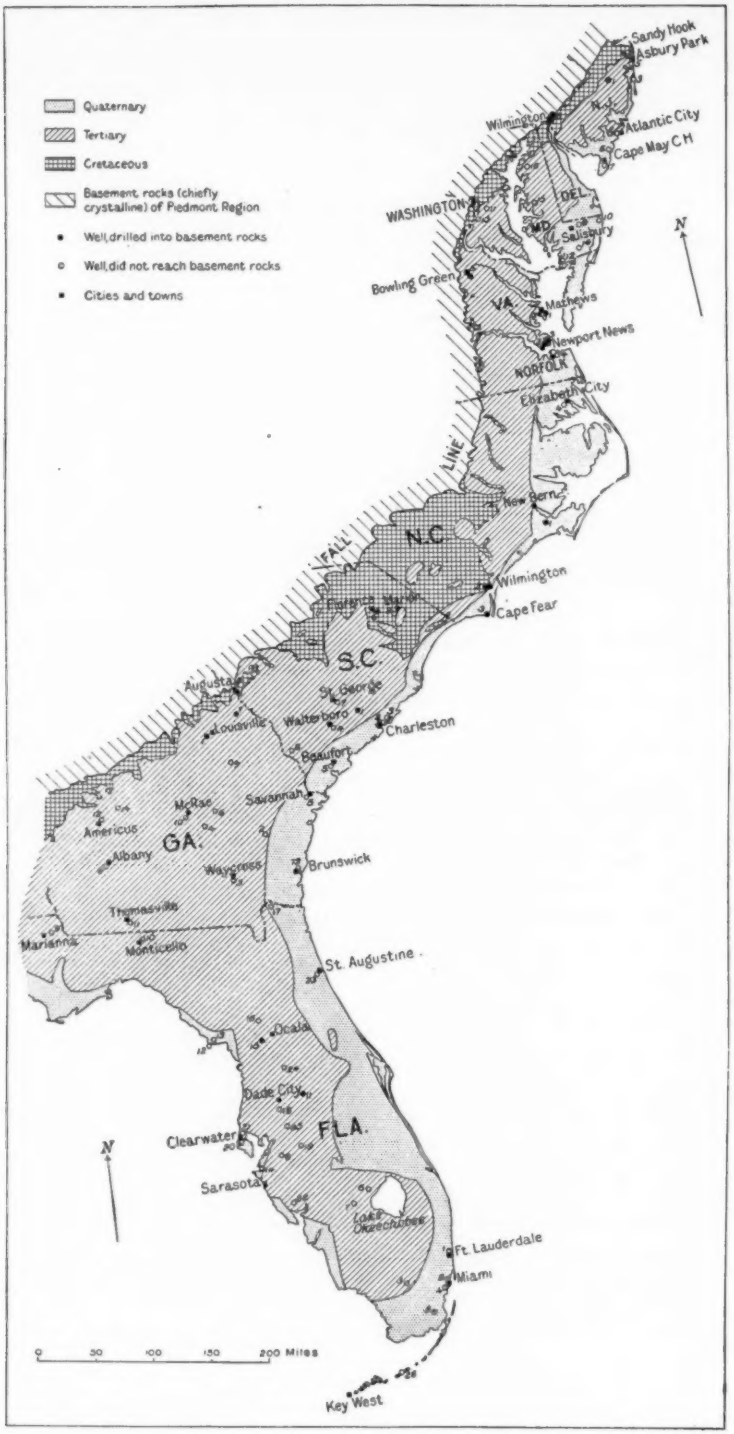


FIG. 1.—Map showing general geology of Atlantic Coastal Plain from New Jersey to Florida, and indicating locations of wells with numbers as referred to in text.

New Jersey southward younger formations progressively overlap older ones and in the Potomac River valley the Upper Cretaceous deposits are completely cut out and the Eocene rests directly on the Lower Cretaceous. Still farther south, in southern Virginia and northern North Carolina, the Miocene deposits overlap both the Cretaceous and the Eocene and rest on the crystalline basement rocks. The Lower Cretaceous is exposed in a narrow belt along the western edge of the Coastal Plain. In New Jersey and Maryland the Lower Cretaceous lies on the basement rocks (predominantly granite and gneiss) of the Piedmont, and in places it is directly overlain by Tertiary and younger beds. The Upper Cretaceous outcrops have their greatest extent in the southern part of North Carolina and the northern part of South Carolina. Locally the Coastal Plain sediments unconformably overlie Triassic deposits that occupy depressions in the crystalline rocks of the Piedmont.

The sediments of the Atlantic Coastal Plain have not, so far as known, been deformed sufficiently to develop local anticlines or domes, such as have been found in the deposits in the Gulf Coast. This lack of local deformation may account, in part, for the barrenness of the Atlantic Coast in comparison with the prolific oil fields on the Gulf Coast of Louisiana and Texas. There is a bare possibility that oil may be found somewhere in the Atlantic Coastal Plain where the Cretaceous and Tertiary formations may be present in sufficient aggregate thickness, especially if any structural or stratigraphic traps can be detected and adequately tested. This is particularly true of southeastern Georgia and southern Florida where little is known of the deeper formations.

The formations of the Atlantic Coastal Plain are, in general, characterized by an absence of thick beds of dark or carbonaceous material, although some dark shales and lignitic beds have been reported in the Lower Cretaceous. The Cretaceous beds are partly non-marine, partly estuarine, and partly marine in origin, and range from a thickness of a few hundred feet in New Jersey to possibly more than 3,000 feet in southeastern Georgia. The Upper Cretaceous is largely composed of sands, clays, and marls. The Tertiary formations, consisting mainly of sands, clays, and marls, with some diatomaceous earths, are little consolidated and apparently have been subjected to practically no deformation.

Traces of oil and gas have been reported in Cretaceous sediments at a few places, notably in a deep well drilled at Summerville, South Carolina, at one locality in Telfair County, Georgia, and more recently in a well in Lake County, Florida.

The known aggregate thickness of sediments at many places along the Atlantic Coast seems entirely insufficient for the formation and accumulation of commercially important amounts of oil. Wells have penetrated the entire series of sediments and reached basement rocks at the places and depths here indicated. The numbers in parentheses refer to numbers in Figure 1 and elsewhere in the text.

In Virginia, near Mathews (1), Mathews County, at a depth of 2,325 feet; at Fortress Monroe (2), Elizabeth City County, at a depth of 2,243 feet; at North End Point (3), not far from Fortress Monroe, at a depth of 1,172 feet; and, as recently reported, at Bowling Green (5), Carolina County, at a depth of 1,750 feet.

In North Carolina, at Wilmington (2), at a depth of 1,109 feet; at Fort Caswell (3), at 1,540 feet; and at Havelock (1), at 2,318 feet.

In South Carolina, at Summerville (1), at a depth of 2,450 feet (reported to have entered diabase of Triassic age); at Florence (6), at a depth of 1,750 feet (reported to have struck "trap rock").

In Georgia, the basement rocks are said to have been reached at Louisville (1), at a depth of 1,143 feet; and south of Augusta (7), at depths of approximately 1,500–1,540 feet.

In Florida, basement schist was found near York (15), at a depth below 4,100 feet; and near the southern border of Lake County (11), granite was reached at approximately 6,100 feet.

One fact that is unfavorable to the hope of finding oil pools in the Atlantic Coastal Plain is that many wells that have penetrated the Cretaceous formations have encountered fresh water which supplies many artesian wells. It seems probable that such water has invaded the beds at their outcrops along the western edge of the Coastal Plain and has pushed seaward any possible original content of salt water and oil. Salt water, however, has been encountered in some wells as mentioned in the following paragraphs.[3]

As the table shows, no deep salt waters have been recorded in the Coastal Plain in New Jersey except at Cape May Point and Wildwood in the extreme southern part of the State. There is no mention of salt water in the log of the 2,306-foot well at Atlantic City, although, except for the 2,350-foot well at Key West, Fla., that well is the deepest in the entire Atlantic Coastal Plain. Salt water has been reported at Lewes, Del., Pocomoke, Md., in Accomac and Northampton counties on the eastern shore of Virginia, and in Mathews, Gloucester, Elizabeth City, Norfolk and Princess Anne counties on the western shore. In North Carolina salt water is known to have been found by deep wells in Hyde, New Hanover, Columbus and Brunswick counties, and was presumably found in Pasquotank, Tyrrell, Beaufort and Craven counties. In South Carolina it was found in Beaufort and Charleston counties. In

[3] S. Sanford, "Saline Artesian Waters of the Atlantic Coastal Plain," *U. S. Geol. Survey Water-Supply Paper 258* (1910).

Georgia, though it is altogether likely that salt water has been struck, the wells have not been reported.

It is noteworthy that except in North Carolina all the salt water areas are near the sea or in low land bordering the sea coast.

The following statements are quoted from a report on a deep well (2) at Charleston, South Carolina.[4]

The underground waters in the deposits in the Coastal Plain have been derived from several sources, including water entering from the adjacent Piedmont Plateau, rainfall on the Coastal Plain and originally included sea water. . . . The more deeply buried beds also contain water composed of a mixture of originally included sea water and subsequently included alkaline land water, both of which may properly be classed as fossil waters.

The formations of the Coastal Plain in the several states bordering the Atlantic from New Jersey to Florida have been described in detail in reports of the respective State organizations and in a number of reports of the Federal Survey, mention of which will be found in the list of references. Material from these publications has been used by the writer and grateful acknowledgment is made to the several authors, as well as to H. D. Miser and L. W. Stephenson, who have critically read the manuscript and made helpful suggestions.

Under separate state headings, attention has been given to those wells that have penetrated formations at depths of more than 1,000 feet. The discussion of the more northern states, where the possibilities of finding oil are believed to be much less than farther south, is correspondingly brief.

NEW JERSEY

Lower and Upper Cretaceous, Tertiary, and younger formations in New Jersey are in general unconsolidated sands, clays, and marls which slope gently toward the east-southeast and are practically undeformed. Fresh water is found in them at several horizons. These sediments are underlain by the crystalline rocks of the Piedmont and in some localities by rocks of Triassic age. In places the Raritan of Upper Cretaceous age crops out in thin wedges against the Piedmont rocks or overlaps the Triassic sediments or diabase. Tertiary deposits overlying the Cretaceous and overlain by younger sediments are widely distributed in the southern part of the state.

Although a few wells have been drilled in the hope of finding oil or gas, none has been successful and the prospects for such discoveries in the state are regarded as far from bright. An oil prospecting well

[4] L. W. Stephenson, "The Cretaceous-Eocene Contact in the Atlantic and Gulf Coastal Plain," *U. S. Geol. Survey Prof. Paper 90-J* (1915).

(1) at Prospertown in northwestern Ocean County was reported to have struck crystalline rock 1,100 feet below the surface.

A deep well (2) was drilled on Young's Pier at Atlantic City to a depth of about 2,306 feet without reaching the Raritan. Scant supplies of water were encountered at depths of 950, 1,250, and 2,150 feet. A well (3) at Lavallette, in Ocean County near Seaside Park, was drilled to a depth of 1,551 feet, and one (4) at Asbury Park was drilled to 1,321 feet, but neither encountered fresh water below 1,135 feet. Several wells at Asbury Park were drilled to depths between 1,050 and 1,135 feet and encountered fresh water at several horizons. The New Jersey Department of Conservation and Development has published a summary on New Jersey geology[5] as well as papers dealing with underground water, one of which contains a record of the well at Young's Pier.[6]

Other wells drilled in the state to depths of more than 1,000 feet are as follows: (5) Ocean Grove, Monmouth County, depth 1,134 feet; (6) Wildwood, Cape May County, depth 1,244 feet; (7) Cape May, Cape May County, depth 1,313 feet.

DELAWARE

In Delaware the Cretaceous thins out against the ancient crystalline rocks of the northern part of the state but on the south-southeast is transgressed by progressively younger deposits, similar to those in New Jersey. This state, like New Jersey, is regarded as offering practically no chance for the discovery of oil or gas in large quantities. News items appeared in 1934 to the effect that a well drilled in Sussex County on the "Delaware Apple Orchard" tract had struck at least traces of oil at a depth of 400 feet. So far as is known to the United States Geological Survey these reports were never substantiated, and no further information about the well is available. A well (8) drilled at Wilmington to a depth of 1,077 feet was reported to have been in granite from 96 to 1,077 feet.

MARYLAND

The general geology of eastern Maryland has been described in several reports of the Maryland Geological Survey, notably Vol. X,

[5] J. Volney Lewis and Henry B. Kümmel, "The Geology of New Jersey," *New Jersey Geol. Survey Bull. 14* (1915), 146 pp., 2 pls.

[6] David G. Thompson, "Ground Water Supplies of the Atlantic City Region," *New Jersey Dept. Conserv. Devel. Bull. 30* (1928), 138 pp., 7 pls.
Idem, "Ground Water Supplies in the Vicinity of Asbury Park," *ibid.*, *Bull. 35* (1930), 50 pp.

Pt. II, dealing with surface and underground water resources of Maryland.[7]

It is believed that the Lower Cretaceous formations in Maryland were deposited largely under continental conditions; in some of them lignitized tree trunks have been found. The Upper Cretaceous deposits are estuarine and marine in origin and unconformably overlie the Lower Cretaceous. The Tertiary formations, which are well represented in Maryland, rest unconformably on the Cretaceous and overlap them toward the western edge of the Coastal Plain.

There have been reports, from time to time, of discoveries of oil and gas showings in eastern Maryland and, years ago, some gas was encountered at shallow depths in a few wells in Wicomico County. On examination, the gas did not appear to be of a type that would indicate association with petroleum. Small quantities of the gas were used on some of the farms for household purposes but no large amounts of gas were ever developed. An oil prospecting well (9) was drilled at Parsonsburg in Wicomico County, to a depth of 1,130 feet, encountering highly mineralized water. In 1914 a well (10) was drilled in search for oil on the Isle of Wight, Worcester County, to a depth of 1,706 feet, where it encountered water high in chlorides and sulphates, probably "fossil" water in the Miocene. Another well (11) was drilled for oil during the time of the World War, just east of Washington on the Marlboro Pike in Prince George County. At a depth of about 1,400 feet it was believed to have been in crystalline rocks. Several wells (12) drilled in the vicinity of Crisfield, in Somerset County, went to depths between 1,018 and 1,260 feet, probably reaching the Lower Eocene or Upper Cretaceous. A well (13) at Fort Washington entered rocks of the Potomac group at 1,000 feet, and one (14) at Pocomoke in Worcester County was probably in the Eocene at a depth of 1,500 feet. At Easton, Talbot County, a town water-supply well (15) reached a depth of 1,015 feet, and one at Chestertown (16) Kent County, went to 1,135 feet and encountered salt water.

VIRGINIA

The sediments in the Coastal Plain of Virginia range in age from Lower Cretaceous to Recent and have been described in reports published by the State Survey. As indicated on the geologic map of the state, the Lower Cretaceous crops out in Virginia in small extent, except in the northeastern part of the state in the Potomac Valley. In

[7] W. Bullock Clark, E. B. Mathews, and E. W. Berry, "The Surface and Underground Water Resources of Maryland, Including Delaware and the District of Columbia," *Maryland Geol. Survey*, Vol. 10, Pt. II (1918).

the greater part of the Coastal Plain the Lower Cretaceous is transgressed by Tertiary deposits, and the Upper Cretaceous formations are known in Virginia only in deep well borings.

The Cretaceous and Tertiary formations yield supplies of fresh water in Virginia, and no wells anywhere in the state have encountered oil or gas in quantity. Indications of gas were reported some years ago in Mathews County and in 1929 a well (1) was drilled in search for oil or gas near Mathews in that county. It reportedly went to a depth of 2,325 feet, penetrating the entire thickness of sedimentary deposits and entering the basement granite; but it failed to encounter even traces of oil or gas.

A well (2) drilled at Fortress Monroe to a reported depth of about 2,250 feet encountered salt water at 1,320 feet and basement rock at 2,131 feet. Another well (3) at North End Point, "about 6 miles northeast of Fort Monroe," was said to have reached "granite" at 1,172 feet. One at Mathews (1), in Mathews County, struck basement rock at 2,325 feet. One (4) at Moores Bridge (Norfolk) encountered salt water at 1,072 feet. Information recently acquired by one of the geologists of the United States Geological Survey working in the region, is to the effect that basement rock has been encountered at a depth of 1,750 feet at Bowling Green (5) in Caroline County.

NORTH CAROLINA

The Coastal Plain of North Carolina consists of deposits ranging in age from Cretaceous to Pleistocene and Recent, with a general dip toward the ocean. The Cretaceous formations are widely present at the surface in the southern part of the Coastal Plain of the state. Northward these deposits are more and more concealed by younger formations until at the Virginia line the Cretaceous strata are completely blanketed by overlying deposits. A comprehensive report on the geology of the North Carolina Coastal Plain was prepared by the United States Geological Survey in coöperation with the State, and published in 1912 by the North Carolina Survey as its Volume 3.[8]

Cretaceous deposits are well exposed in the valley of the Cape Fear River, and, in the State report, L. W. Stephenson expressed the opinion that the course of the Cape Fear River across the Coastal Plain approximately marks the axis of a broad structural uplift dating from the interval marked by the unconformity between the Cretaceous and Tertiary sediments.

In a report on the oil prospecting well (1) near Havelock, in

[8] L. W. Stephenson, "The Cretaceous Formations of North Carolina," *North Carolina Geol. Econ. Survey*, Vol. 3 (1912), pp. 73–147.

Craven County, W. C. Mansfield[9] has included the following statement.

> Three of the wells, Great Lakes well No. 2, that at Wilmington, N. C., and the well at Summerville, S. C., lie about in a straight line trending north 56 degrees east, and this line is approximately parallel both to the coast and to the line marking the inner edge of the Coastal Plain. Wilmington is about 150 miles from Summerville and about 65 miles from the Great Lakes well No. 2. The records of these wells, therefore, show that the surface of the basement rock at Wilmington lies about 1,200 feet higher than it normally would be expected to lie on the assumption of a uniform dip of this surface, and this fact together with the surface distribution of the geologic formations seems to verify the opinion of Stephenson that the course of Cape Fear River across the Coastal Plain approximately marks the axis of a broad structural uplift, dating from the interval marked by the unconformity between the Cretaceous and Tertiary sediments, and the uplifted position has been maintained without marked subsidence uptil the present. It follows also that the Great Lakes No. 2 is located in a downwarped area, for the Cretaceous-Eocene contact, which at Wilmington is a few feet above sea level, was reached in the Great Lakes well at a depth of 684 feet, showing a relative down-sinking of nearly 700 feet of the old Cretaceous-Eocene erosion surface. Summerville is also in a downwarped area for there the Cretaceous-Eocene contact lies at a depth of about 700 feet.

No real showings of oil or gas have been found in North Carolina and no structural or stratigraphic traps favorable to the accumulation of oil are known to exist in the deeper sediments. Further drilling in these deeper sediments will be required to supply definite information on such conditions in eastern North Carolina.

A well (2) drilled at Wilmington, New Hanover County, reportedly encountered granite at 1,109 feet, but was drilled several feet deeper; one (3) at Fort Caswell, Brunswick County, was drilled to approximately 1,540 feet and was said to have encountered crystalline rock; and Great Lakes well No. 2, at Havelock, mentioned in the foregoing quotation, encountered the basement rocks at 2,318 feet. A well (4) drilled at Elizabeth City, Pasquotank County, also near the ocean, reached a depth of 1,207 feet and encountered salt water.

SOUTH CAROLINA

In South Carolina the sediments of the Coastal Plain range from Upper Cretaceous to Recent in age, no Lower Cretaceous deposits being known in the state. Of the Upper Cretaceous, C. W. Cooke[10] makes the following statement.

[9] W. C. Mansfield, "Oil Prospecting Well Near Havelock, North Carolina," *State of North Carolina Depart. of Conserv. Develop. Econ. Paper 58* (1927).

[10] C. W. Cooke, "Geology of the Coastal Plain of South Carolina," *U. S. Geol. Survey Bull. 867* (1936).

> The Upper Cretaceous of South Carolina is divisible into three formations, the Tuscaloosa at the base, the Black Creek in the middle, and the Peedee at the top. Each of the three formations is distinguished from the others by its peculiar lithology and is separated from the deposits above and below it by erosional unconformities. The Tuscaloosa consists chiefly of light-colored cross-bedded sand and lenses of massive light-colored clay and kaolin. It rests upon the ancient crystalline rocks of the Piedmont region. The Black Creek formation, which lies unconformably upon the Tuscaloosa, is much darker than the Tuscaloosa. Its lower part is chiefly very dark gray to black leaf-bearing clay and sand; its upper part, the Snow Hill marl member, is more sandy and contains marine shells. An unconformity . . . separates it from the overlying gray sandy marl and marlstone of the Peedee formation.

At another place in the same report Cooke states that a few thin seams of lignite and carbonaceous clay have been noted in the Upper Cretaceous Black Creek formation and in the Eocene Black Mingo formation, but that no indications of the presence of petroleum or natural gas have been discovered in South Carolina.

No discoveries have been made, so far as information is available, of any local structures—anticlines or domes—in the deeper sediments along the coast of South Carolina, and no residues of bituminous matter have been found in the outcrops or in deep wells. All of the formations in the Atlantic Coastal Plain of South Carolina yield water for wells or are known to contain fresh water.

In 1920 or 1921 a well (1) was drilled in search for oil at Summerville, Dorchester County, to a depth of 2,570 feet, where it was reported to have penetrated diabase of Triassic (?) age. From cuttings submitted to the Geological Survey, it appeared that the well went through approximately 300 feet of Tertiary sediments and more than 1,200 feet of Upper Cretaceous, overlying apparently Triassic (?) igneous rocks. This well was inspected by the late E. W. Shaw, and in a press notice issued by the United States Geological Survey he made the following statement.

> It seems probable from all that can be learned of the well and the surrounding country, using both the practical facts concerning kinds of places where oil has been found the world over and theoretical considerations as to the kind of places where one may expect to find it, that any oil and gas found in the region around Charleston will probably come from small pockets or lenses in sand that is enclosed in dark clay. Several formations in this region contain partly decomposed organic matter from which oil and gas might be generated and under proper geological conditions made to accumulate in lenses of sand that are shut in by relatively impervious clay.

In May, 1911, a well (2) completed in Charleston, Charleston County, at the foot of Charlotte Street, reached a depth of 2,001 feet, penetrating marine formations of Tertiary and Cretaceous age

consisting of sand, clay, marls, and impure limestones. Basement rock was not reached. A record of this well is given in *Professional Paper 90-j*, of the United States Geological Survey. To a depth of 454 feet, the strata penetrated are of Tertiary and more recent age; from 454 to 750 feet, the age of the strata was not definitely determined but they are either Upper Cretaceous or Eocene; and from 750 feet to the bottom of the well only Upper Cretaceous deposits were encountered. All Cretaceous and Tertiary deposits penetrated by the well were reported to be marine in origin.

Other records of wells in the Coastal Plain are as follows.

A well (3) drilled on Sullivans Island, Charleston County, was reported to have reached a depth of 1,950 or 2,000 feet; the Walterboro, Colleton County, city water-supply well (4) went to 1,515 feet, probably into Upper Cretaceous; a well (5) at Port Royal, Beaufort County, was reported to have been in quicksand at 1,640 feet; one (6) at Florence, Florence County, reached a depth of 1,750 feet; one (7) at St. George, Dorchester County, was drilled to 1,355 feet; at Garnett (8), Hampton County, the Tuscaloosa (Upper Cretaceous), was reported at 1,022 feet, and the same formation was said to have been penetrated at 1,200 feet at Marion (9), Marion County.

GEORGIA

In Georgia the sediments of the Coastal Plain range in age from Tuscaloosa (Upper Cretaceous) to Recent. No Lower Cretaceous deposits are known in the state. They overlie the igneous and metamorphic rocks of the Piedmont Plateau and dip south and southeast. Somewhat north of the Florida line, the strata flatten and, at the state boundary, they appear to be inclined north-northwest. The slope of the surface, independent of the dip of the formations, is approximately 3 feet to the mile from the Fall Line to sea-level. The southeast slope of the crystalline floor at the Fall Line ranges from 30 to 75 feet to the mile but the average slope to the coast has not been determined.

No great structural deformation of the deposits of the Coastal Plain is known but a few broad flexures have been noted. These were described by Veatch in *Bulletin 26*[11] of the Georgia Survey. Veatch stated that the nature of the drainage, together with certain geologic facts, suggests that Chattahoochee River occupies the crest of a southward pitching low anticline. The stream has held its course and cut its channel down through the rising strata and belongs,

[11] Otto Veatch and L. W. Stephenson, "Preliminary Report on the Geology of the Coastal Plain of Georgia," *Georgia Geol. Survey Bull. 26* (1911), 466 pp., 30 pls., 2 maps.

therefore, to the class of antecedent streams. He stated further that the geologic evidence of an anticline is afforded by the greater erosion and consequent exposure of the geologic formations along the Chattahoochee River. He suggested also that the low arch or fold indicated in the area drained by the Withlacoochee, Ochlockonee, and Alapaha rivers may have been involved in the same movement that produced the "Chattahoochee anticline." Some years ago the Federal Survey examined the reported area of uplift along the Chattahoochee River from Columbus to the Florida line and in the press notice concerning these studies the following statement is made.

> Although it is not possible at this time to describe in detail the structure of the areas considered, it may be stated that the evidence of the existence of anticlinal folds is unsatisfactory and inadequate and affords no sufficient ground for drilling for oil.

According to a recent oral statement of L. W. Stephenson, the existence of a broad though slight upbowing of the strata in the Chattahoochee region affecting southwest Georgia and southeast Alabama can hardly be disputed. It is indicated by the distribution of the formations and the narrow gorge of relatively recent date cut by the Chattahoochee River.

In 1923 the Georgia Geological Survey published as its *Bulletin 40*[12] a report on the oil and gas possibilities of the state, with a generalized structure map. The authors state that laboratory tests of some Cretaceous and Tertiary formations in Georgia have yielded traces of oil. However, no oil or gas in quantity has been found anywhere in Georgia.

The Cretaceous deposits, so far as known, consist of sand, clay, gravel, impure limestone, and some sandy calcareous marl, and the Tertiary beds are composed of sand, clay, marl, and limestone. No wells have penetrated the entire thickness of the deposits of the Coastal Plain in southeast Georgia and the deeper formations in that area are not known. It is possible that some of them may be oil-bearing, but drilling for oil in this area can only be regarded as distinct "wildcatting."

The first test for oil in Georgia was made by A. F. Lucas southwest of Louisville, in Jefferson County. The well (1) was shut down at a depth of 500 feet and later drilled to a depth of 1,143 feet by the Georgia Petroleum Oil Company. It was reported to have encountered

[12] T. M. Prettyman and H. S. Cave, "Petroleum and Natural Gas Possibilities in Georgia," *Georgia Geol. Survey Bull. 40* (1923), 164 pp., 8 pls., 3 maps.

crystalline rocks, having penetrated approximately 790 feet of Cretaceous rocks.

A well (2) was drilled in search of oil near Doctortown in Wayne County to 1,901 feet, and probably reached the Eocene, or Upper Cretaceous. It was reported to have been in glauconitic sand at the bottom of the hole.

A well (3) drilled by the Waycross Oil and Gas Company in Ware County south of Waycross, at Fredel, was reported to have reached a depth of approximately 3,040 feet and to have encountered slight traces of oil and salt water at depths below 2,000 feet. There is apparently no record to indicate definitely that the well reached the Cretaceous, but L. W. Stephenson is of the opinion that it did.

A test (4) was made for oil 12 miles west of Hazelhurst, in Jeff Davis County, and reached a depth of 1,975 feet, probably in Upper Cretaceous strata. "Oil traces" were reported in the Ripley formation.

At Cherokee Hill (5) in Chatham County, 6 miles northwest of Savannah, an oil prospecting well was drilled to a depth of 2,130 feet, and reached the Upper Cretaceous. It was reported to have encountered a little gas at 1,000 feet, a showing of oil at 1,590 feet, and salt water at 2,000 feet.

An artesian well (6) in Albany, Dougherty County, reached a depth of 1,320 feet. It was drilled into Upper Cretaceous sand.

Three wells (7), approximately 20 miles south of Augusta, in Burke County, were reported to have encountered granite at depths of 1,500, 1,540, and 1,560 feet. Showings of oil were reported in one of the wells.

In May, 1937, it was reported in the *Oil Weekly* that a well (8) near Uvalde, in Montgomery County, had reached a depth of 1,585 feet and there was a rumor that an oil showing was encountered at 1,542–47 feet.

A well (9) at Graymont, Emanuel County, was drilled to a depth of 2,232 feet, and one (10) in Wheeler County, near McRae, was abandoned at a depth of 3,384 feet. Other wells that may be mentioned are: one (11) at Thomasville, Thomas County, which was reported to have been in limestone at a depth of 1,680 feet and then to have encountered quicksand at 1,820 feet; an artesian well (12) at Americus, Sumter County, which was drilled to a depth of 1,725 feet; several wells (13) at Brunswick, Glynn County, which encountered artesian water at a depth of approximately 1,000 feet (the depth to the basement rocks in this county is believed to be 3,000 feet or more); and a well (14) at Byromville, Dooly County, which was re-

ported to have encountered marl, probably of the Ripley formation, at a depth of 1,100 feet.

In 1919 the Georgia Survey published a short report[13] on an oil seepage near Scotland, Telfair County, and in the conclusions is the following statement of the State geologist.

> In view of the fact that a natural seepage of oil occurs in the vicinity of Scotland together with suggestions of structure, I am of the opinion that one or more test wells should be put down in that locality, as the drill alone must finally be resorted to before the area can be actually proved or disproved. A test well, unless oil should be found at higher elevations, should be extended to crystalline rock which will be encountered possibly at about 3,000 feet.

FLORIDA

The general geology of Florida has been described in reports published by the Federal and State surveys. The Upper Cretaceous formations are believed to overlie directly the basement rocks in Florida, since no Lower Cretaceous deposits have been found in well cuttings. Overlying the Upper Cretaceous are deposits of Tertiary and more recent age. The Cretaceous and Tertiary sediments in Peninsular Florida consist predominantly of limestones but thin seams of lignitic material have been found in some of the Tertiary formations. Recently a well in Lake County encountered a thick section of anhydrite.

In this paper no attention has been given to western Florida, where the formations are of somewhat different types from those in the eastern and southern parts of the state.

The following two paragraphs are quoted from the coöperative report on the geology of Florida published in 1929 by the State Survey.[14]

> The Floridian Plateau has been in existence since very ancient time. It appears to have formed part of Appalachia, the old land mass that lay east of the epicontinental seas during the Paleozoic era, for metamorphic rocks have been found in deep well borings in Florida. It probably remained dry land during the Triassic and Jurassic periods and the Lower Cretaceous epoch, but it was covered by the sea during part of Upper Cretaceous time.
>
> . . . . . .
>
> As Florida is far from the Piedmont Plateau, which was the original source of all the sand, gravel and clay in the rocks of the southeastern part of the Coastal Plain, the sediments deposited on the Floridian Plateau have generally contained less sand, clay or gravel than limestone, which is carried in solution in sea water. These sediments were especially calcareous during Eocene and part of Oligocene time, when the shore line lay not far from the

[13] J. P. D. Hull and L. P. Teas, "A Preliminary Report on the Oil Prospect Near Scotland, Telfair County, Georgia," *Georgia Geol. Survey* (1919).

[14] C. Wythe Cooke and Stuart Mossom, "Geology of Florida," *Florida Geol. Survey 20th Ann. Rept.* (1929), pp. 29–228.

present edge of the Piedmont Plateau and when the sediments formed were nearly pure limestones. During the Miocene epoch more sand, most of it fine-grained, found its way southward and became mingled with the limestone to form sandy limestone, and during the later epochs the stores of sand and clay in the Coastal Plain of Alabama, Georgia and the Carolinas supplied much material to the northern part of the Floridian Plateau and some sand and clay drifted as far southward as the tip of the Peninsula.

The formations in Florida are in general undeformed, although in the north-central part of the state a broad doming of the strata has been designated as the Ocala uplift. No locally developed anticlines or domes or other traps favorable to the accumulation of oil are known to exist in the Cretaceous or Tertiary formations. These in the southern part of the state are completely concealed by deposits of Pleistocene and Recent age.

A well (15) drilled on the Ocala uplift near York, in Marion County, reached a depth of 6,180 feet, penetrating the basement (metamorphic) rocks below 4,100 feet, and another well (16), near Fairfield, in the same county, was drilled to 4,334 feet. The formations encountered in both these wells were predominantly limestones.

Recently it has been reported that "granite" was encountered at a depth of about 6,100 feet in a well (11) drilled in Sec. 17, T. 24 S., R. 25 E., Lake County. "Shows" of oil were reported at several depths in this well. It penetrated "a massive anhydrite section" which, with occasional breaks, was reported from 632 feet to 3,066 feet.

A well (10) at Monticello, Jefferson County, was reported to have encountered Upper Cretaceous at 2,252 feet, and from that depth to the bottom of the well, at 3,838 feet, shales with some "chalk and sandy lime" were recorded. The driller reported slight "gas shows" at 3,400 feet but only salt water at the bottom of the well.

Thousands of shallow wells have been drilled for water throughout Florida and a number of wells have been drilled in search for oil and gas. However, neither oil nor gas has been discovered in commercial quantities in the state.

In recent years it has been reported that some companies have been conducting geophysical surveys in parts of Florida, notably in the Everglades.

Probably the two deepest wells drilled in the state in search for oil are the one in Marion County, Sec. 10, T. 16 S., R. 20 E., 6,180 feet in depth, which was said to have encountered basement rocks between 4,000 and 4,700 feet below the surface; and the one in Sec. 17, T. 24 S., R. 25 E., Lake County, which is reported to have reached a depth of 6,129 feet and to have encountered granite at about 6,100 feet.

Deep wells that have been drilled in Florida since 1925 are as follows.

County		*Nearest town*	*Depth*
1. Broward		Fort Lauderdale	3,010
2. Dade		Miami	5,600
3. Dade	Sec. 19, T. 54 S., R. 35 E.		4,565
4. Dade	Sec. 12, T. 55 S., R. 40 E.	Kendall	5,428
5. Dade		Florida City	2,080
6. Glades	Sec. 15, T. 39 S., R. 32 E.		2,500
7. Glades		Palmdale	2,773
8. Hillsborough	Sec. 4, T. 32 S., R. 21 E.		2,625
9. Jackson	Sec. 15, T. 5 N., R. 9 W.	abandoned 1936	5,022
10. Jefferson		Monticello	3,838
11. Lake	Sec. 17, T. 24 S., R. 25 E.	believed abandoned 1937	6,129
12. Levy		Cedar Keys	1,000
13. Levy	Sec. 9, T. 15 S., R. 13 E.		4,010
14. Manatee		Palmetto	2,765
15. Marion	Sec. 10, T. 16 S., R. 20 E.	York ? (on Ocala Uplift)	6,180
16. Marion	Sec. 25, T. 13 S., R. 20 E.	Fairfield ? (on Ocala Uplift)	4,334
17. Nassau	Sec. 19, T. 4 N., R. 24 E.	(in hard sticky shale and gumbo—still drilling)	3,808
18. Pasco		Zephyr Hills	1,020
19. Polk	Sec. 28, T. 30 S., R. 23 E.	Bartow ?	4,540
20. Pinellas		Clearwater	1,005
21. Pinellas		Clearwater	1,475
22. Sarasota		Murdock	1,332
23. St. Johns	Ponce de Leon Hotel	St. Augustine	1,390
24. Sumter	2½ miles south of Post Office	Sumterville	2,002
25. Hillsborough	Sec. 2, T. 29, R. 22	Plant City	1,100
26. Monroe		Marathon	2,555

BIBLIOGRAPHY

DARTON, N. H., "Artesian-well Prospects in the Atlantic Coastal Plain Region": U. S. Geol. Surv., Bull. 138, 232 pp., 19 pls. 1896.

STEPHENSON, L. W., "The Cretaceous-Eocene Contact in the Atlantic and Gulf Coastal Plain": U. S. Geol. Surv., Prof. Paper 90-j, pp. 155–182, pls. xi–xix. 1915.

MANSFIELD, W. C., "Some Deep Wells near the Atlantic Coast in Virginia and the Carolinas": U. S. Geol. Surv., Prof. Paper 186-i, pp. 159–161. 1937.

FULLER, M. L., CLAPP, F. G., MATSON, G. C., SANFORD, SAMUEL, and WOLFF, H. C., "Underground-Water Papers": U. S. Geol. Surv., Water-Supply Paper 258, 123 pp., 2 pls. 1911.

STEPHENSON, L. W. and VEATCH, J. O., "Underground Waters of the Coastal Plain of Georgia": U. S. Geol. Surv., Water-Supply Paper 341, 539 pp., 21 pls. 1915.

FULLER, M. L., LINES, E. F., and VEATCH, A. C., "Record of Deep-Well Drilling for 1904": U. S. Geol. Surv., Bull. 264, 106 pp. 1905.

FULLER, M. L., and SANFORD, SAMUEL, "Record of Deep-Well Drilling for 1905": U. S. Geol. Surv., Bull. 298, 299 pp. 1906.

COOKE, C. WYTHE, "Geology of the Coastal Plain of South Carolina": U. S. Geol. Surv., Bull. 867, 196 pp., 18 pls. 1936.

LOHMAN, S. W., "Geology and Ground-Water Resources of the Elizabeth City Area, North Carolina": U. S. Geol. Survey Water-Supply Paper 773-a, pp. 1–57. 1936.

STRINGFIELD, V. T., "Artesian Water in the Florida Peninsula": U. S. Geol. Survey Water-Supply Paper 773-c, pp. 115–195. 1936.

COOKE, C. WYTHE, and MOSSOM, STUART, "Geology of Florida": Twentieth Annual Report of the Florida State Geol. Survey, pp. 29–228. 1929.

VEATCH, OTTO, and STEPHENSON, L. W., "Geology of the Coastal Plain of Georgia": Geol. Survey of Georgia, Bull. 26, 466 pp., xxx pls., 2 maps. 1911.

PRETTYMAN, T. M., and CAVE, H. S., "Petroleum and Natural Gas Possibilities in Georgia": Geol. Survey of Georgia, Bull. 40, 164 pp., 8 pls., 3 maps. 1923.

MCCALLIE, S. W., "Preliminary Report of the Underground Waters of Georgia": Geol. Survey of Georgia, Bull. 15, 370 pp. 1908.

CLARK, WM. BULLOCK, *et al.*, "Physiography and Geology of the Coastal Plain Province of Virginia": Va. Geol. Survey, Bull. IV, 274 pp., 19 pls. 1912.

LEWIS, J. VOLNEY, and KUMMEL, HENRY B., "The Geology of New Jersey": Geol. Survey of New Jersey, Bull. 14, 146 pp., 2 pls. 1915.

THOMPSON, DAVID G., "Ground Water Supplies of the Atlantic City Region": New Jersey Dept. of Conservation and Development, Bull. 30, 138 pp., 7 pls. 1928.

THOMPSON, DAVID G., "Ground Water Supplies in the Vicinity of Asbury Park": New Jersey Dept. of Conservation and Development, Bull. 35, 50 pp. 1930.

STEPHENSON, L. W., "The Cretaceous Formations of North Carolina": N. C. Geol. and Econ. Survey, Vol. 3, pp. 73–147. 1912.

STEPHENSON, L. W., "Major Features in the Geology of the Atlantic and Gulf Coastal Plain": Journal of the Washington Academy of Sciences, Vol. 16, No. 17, October 18, 1926.

CLARK, WM. BULLOCK, MATHEWS, E. B., and BERRY, E. W.: "The Surface and Underground Water Resources of Maryland, including Delaware and the District of Columbia": Maryland Geological Survey, Vol. X, Pt. II. 1918.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 816-822, 2 FIGS.

SCANLAN, OR MIDWAY, DOME, LAMAR COUNTY, MISSISSIPPI[1]

D. J. MUNROE[2]
Hattiesburg, Mississippi

ABSTRACT

The Scanlan, or Midway, dome is 14 miles south of west of Hattiesburg, in Lamar County, Mississippi. The approximate center of the dome is in Sec. 28, T. 4 N., R. 15 W. It is 110 miles northeast of the Sorrento dome in Ascension Parish, Louisiana, the closest producing coastal salt dome. The only other salt dome discovered to date in Mississippi is 96 miles northwest of the Midway dome, in western Hinds County.

Early interest in the area resulted from subsurface correlation between widely separated dry holes. Core drilling and test wells have revealed a domed structure elongate northeast and southwest with several hundred feet of closure. Several wells have found anhydrite and salt.

The Midway dome is a geological prospect. The stratigraphic section of the Eocene does not differ much from that normal for the area unless it is in the scarcity of sand bodies of any consequence. Structurally this is a piercement-type dome, belonging, in the writer's opinion, in the inland rather than the coastal classification. Salt movement had its maximum development in late Tuscaloosa or pre-Eutaw time, but continued until late Oligocene time. The oil accumulation that resulted in the asphaltic sand took place prior to the close of Tuscaloosa time.

LOCATION

The Scanlan, or Midway, dome is located 14 miles south of west of the city of Hattiesburg (Fig. 1). The approximate center of the dome is in Sec. 28, T. 4 N., R. 15 W. It is 110 miles northeast of the Sorrento dome in Ascension Parish, Louisiana, the closest producing coastal salt dome. The only other salt dome discovered to date in Mississippi is 96 miles northwest of the Midway dome, in western Hinds County.

HISTORY

Early interest in this general area resulted from long-distance correlations between a few widely separated dry holes. In December, 1933, A. F. Crider produced a structural map showing his "Waterloo structure" which, while covering parts of six townships, centered in T. 4 N., R. 15 W. On the basis of this map J. G. Hix assembled a block of leases and on this block E. B. Germany drilled the Newman Lumber Company's No. 1 in Sec. 21, T. 4 N., R. 15 W., to a depth of 3,520 feet. Due to the encouraging results of this well, the Sun Oil Company became associated with Germany, and they jointly drilled eleven core holes ranging in depth from 854 feet to 1,402 feet. These revealed a dome structure elongate northeast and southwest with

[1] Read before the Association at New Orleans, March 18, 1938. Manuscript received, April 1, 1938.

[2] Sun Oil Company.

several hundred feet of closure. This was the basis for the location of the Scanlan-Semmes No. 1 in Sec. 28, T. 4 N., R. 15 W., which found all markers high and encountered anhydrite at 1,651 feet and salt at 2,522 feet. Three wells have since been drilled and abandoned in anhydrite (Talley 1, 2, and 3), and a fourth (Talley 4) has been drilled to 8,673 feet and abandoned 23 feet in the salt. This is a record depth for drilling in Mississippi.

FIG. 1.—Map showing location of Scanlan, or Midway, dome.

Drilling to date has not yielded commercial oil or gas. The anhydrite and cap rock have been asphaltic in all wells. Most interesting was the finding of 152 feet (equal to 108 feet if lying flat) of asphaltic sand in Talley No. 3 (Fig. 2).

SURFACE FEATURES

As far as can be ascertained there are no topographic features indicating the presence of the dome. Present indications are that the dome underlies a small part of the Black Creek bottoms and the remainder is under the slopes and ridge dividing Black Creek from Little Black Creek. Aerial maps fail to reveal any salt-dome indications.

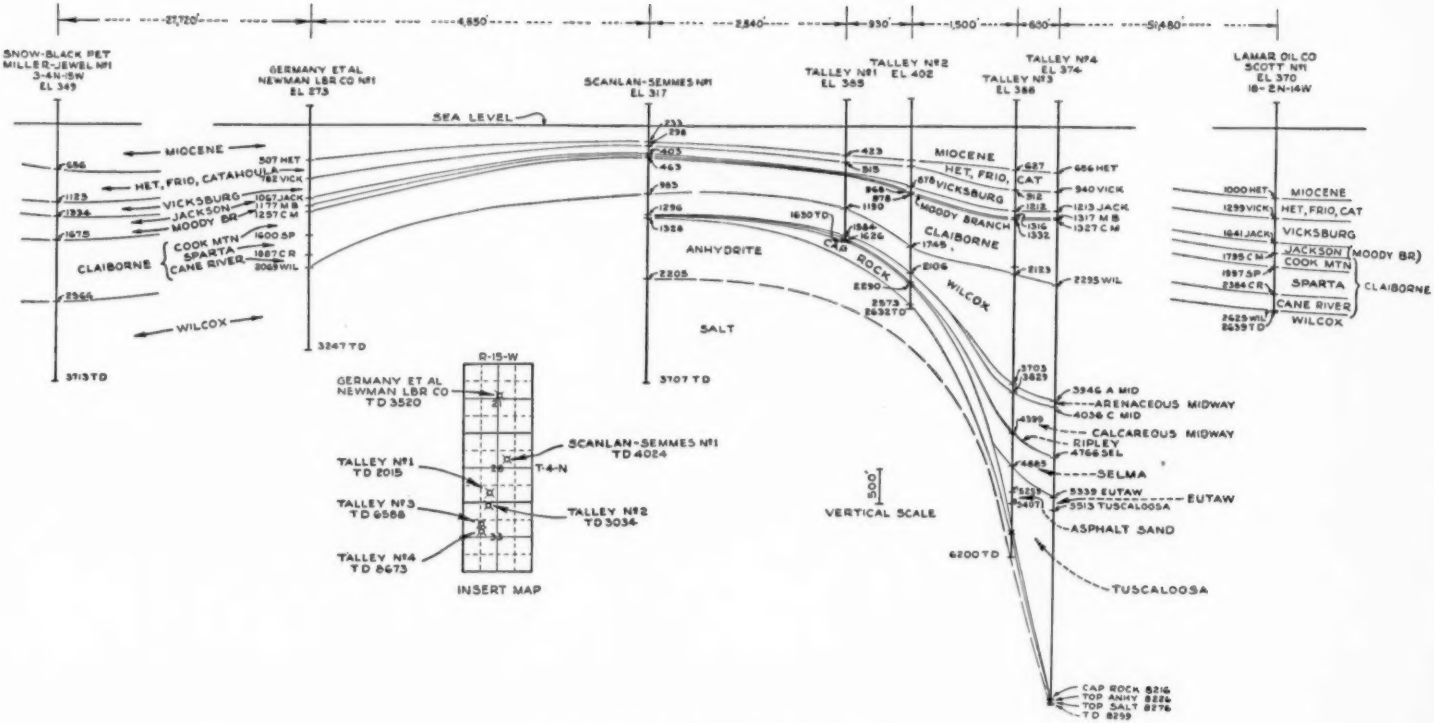


FIG. 2.—Well logs at Scanlan, or Midway, dome.

The total relief in the vicinity of the dome does not exceed 140 feet. All drainage is to Black Creek since that which enters Little Black reaches Black Creek about 3 miles southeast of the dome.

The one feature that might have indicated the top of the dome prior to any core drilling is the absence of water in all shallow sands.

STRATIGRAPHY

The surface material revealed in road cuts and gulleys in the vicinity of the dome is weathered and reworked Citronelle of Pliocene age. The Citronelle is composed essentially of sand and gravel. The beds from the surface to the *Heterostegina* limestone have not been assigned to any group, although, below the Citronelle, the Pascagoula and Hattiesburg formations are undoubtedly present. The first horizon that can be considered a definite marker is the *Heterostegina* zone. This is generally a somewhat pronounced limestone. If careful sampling is maintained a thin black bentonitic shale is found immediately above the zone. The *Heterostegina* zone is a definite and well defined zone paleontologically. The age ascribed to the zone ranges, according to the school of paleontologists followed, from Miocene to Middle Oligocene. The thickness ranges from 10 to 150 feet.

Between the *Heterostegina* zone and the Vicksburg formation is a series of sands, sandy shales, and shales. It has been impossible to pick any definite horizons from this group that can be used for correlation purposes. This series of beds is in the Catahoula-Frio group. In the wells drilled on the dome this series has a variable thickness with the maximum approximately 150 feet.

The Vicksburg formation is composed of limestones, marls, and fossiliferous shales in varying amounts. Its thickness around the dome varies from 105 to 305 feet.

The Jackson series is present in all the wells drilled to date. The strata are predominantly shale with varying amounts of limestone streaks. The thickness of these beds varies from 10 to 120 feet.

The Claiborne is represented by the Cook Mountain and Cane River beds. The writer has been unable to recognize either of the two non-marine members, Yegua and Sparta, which are present a few miles north. The beds present are mainly calcareous shales, marls, and limestones with some sandy shale and here and there a thin sand streak. The color of the shales is predominantly dark gray-to-black. The thickness varies from 500 to 950 feet.

The Wilcox is the typical heterogeneity of sand, shales, sandy shales, marls, and limestones. The entire section seems to be marine as most of the sands cored contain fossils. The first three wells, being

high on the dome, had short sections of Wilcox, 313 feet, 394 feet, and 361 feet, respectively. The last two wells had more nearly the normal, expected thickness of the Wilcox, 1,580 feet and 1,670 feet, respectively. The Wilcox is predominantly dark in color throughout. Practically all sands, and they were few, are shaly. The entire section is micaceous.

The upper part of the Midway is very similar to the Wilcox megascopically, but there is an arenaceous fauna that classes it as Midway. On the dome this zone seems to be approximately 100 feet thick. The remainder of the Midway is typical black shale with a few "lime" streaks and siderite concretions. This calcareous phase has a thickness of 600–700 feet.

The Cretaceous section as now known is made up of the Selma, Eutaw, and Tuscaloosa. The Selma penetrated in the wells on the dome has shown a thin section in all wells. The thickness ranges from approximately 20 feet on top of the dome to 570 feet on the flank (Talley 4). The section is typical, consisting of gray chalk and limestone with the lower part composed mostly of calcareous shale and streaks of limestone.

The Eutaw consists of hard calcareous dark shale, sandy limes, and calcareous sands. This formation is thinner than would be expected. Whether this thinness is due to faulting, or squeezing out, or whether it is normal for this part of Mississippi, will take more wells to determine.

The Tuscaloosa formation has been definitely established in Talley 4. The writer is firmly of the opinion that the asphaltic sand in Talley 3 is Tuscaloosa or older, and if of Tuscaloosa age, then older than our now recognized Tuscaloosa. In Talley 4 more typical Tuscaloosa was encountered. However, the paucity of good sands is very conspicuous in the upper part of the section. Few sands have been found and most of them are quite shaly.

STRUCTURAL GEOLOGY AND HISTORY

The subsurface structure of the Midway dome, as revealed by the core holes, is a dome elongate northeast and southwest with approximately 400 feet of closure. The deeper structure is much more pronounced (Fig. 2). There is evidence of strong uplift in the thinning of the formations, and in their present position far above their normal position. The true structural picture for the entire outline of the dome will have to await additional drilling.

During late Tuscaloosa or pre-Eutaw time there was considerable movement of the salt plug. This is indicated by a comparison of the type of material below the so-called Eutaw encountered in Talley 3 with that in Talley 4. Movement of the salt plug evidently continued until late Oligocene time as formations as young as the *Heterostegina* zone are involved in the structural deformation. This is distinctly different from the salt dome newly discovered at Edwards, in Hinds County, Mississippi, where it is doubtful if any movement took place after Cane River time since all formations younger than Cane River seem to be in their normal position.

OIL AND GAS ACCUMULATION

None of the wells drilled has revealed indications of accumulation of either oil or gas in commercial quantities. They have all revealed some asphalt in the cap rock or anhydrite. The Talley 3 encountered 152 feet of solid asphaltic sand, and several sands below this main body showed asphaltic content.

The cap rock has been tested by drill stem and revealed considerable quantities of warm brackish sulphur water. No sulphur has been found on the dome.

The Cretaceous sands tested seemed to be relatively free of water.

Concerning the asphaltic sand, the writer advances this possibility. Migration and accumulation had been accomplished and completed prior to the cessation of Tuscaloosa deposition. After the uplift and as erosion brought the sand body closer to the surface, the lighter constituents began to escape. When the sand body itself was finally exposed there remained only an asphaltic sand. It seems likely that in the later phases of the erosion period the top of the dome was under subaerial or submarine erosive conditions.

SUMMARY

The Midway dome was discovered by geological methods. The stratigraphic section of the Eocene does not differ much from that normal for the area unless it is in the scarcity of sand bodies of any consequence. Structurally this is a piercement-type dome, belonging, in the writer's opinion, in the inland, rather than the coastal classification. Salt movement had its maximum development in late Tuscaloosa or pre-Eutaw time, but continued until late Oligocene time. The oil accumulation that resulted in the asphaltic sand took place prior to the close of Tuscaloosa time.

The two most important facts brought out by the Midway dome are (1) the definite establishment of a salt dome basin in central Mississippi and (2), through the finding of 152 feet of asphaltic sand, the proof of the former presence of source beds of sufficient extent to yield oil in large quantities. Whether the Midway dome will eventually be found to be commercially productive only future drilling can reveal.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 823-833, 4 FIGS.

APPLICATION OF PRINCIPLE OF DIFFERENTIAL SETTLING TO TRACING OF LENTICULAR SAND BODIES[1]

JOHN L. RICH[2]
Cincinnati, Ohio

ABSTRACT

Because sand is much less compactible than clay, thick lenses of sand surrounded by shale, when buried under a load of later sediments, are marked by low anticlinal bulges. This principle has been used successfully for several years in Kansas for tracing lenticular sand bodies of both the channel and the offshore-bar types. Extremely detailed structural mapping is necessary to reveal these bulges, and they can not always be distinguished from similar structures produced by other causes. Good exposures of evenly bedded rocks at the surface are essential, and lenticular sands at horizons above that at which production is sought may be a source of confusion. Elimination of regional dip is a valuable aid in interpretation. While it seems that every thick sand body is represented by a bulge, not every structural feature which might be so interpreted represents a buried sand body. Consequently, the experience and judgment of the geologist play a large part in the successful use of this method.

INTRODUCTION

Since mud, when first deposited, contains a large percentage of water, it is subject to a large shrinkage in volume as the water is squeezed out by the weight of overlying sediments and the mud is compacted into shale. Sand, on the other hand, shrinks very little since the grains are rigid enough to maintain the interstitial spaces against all ordinary pressures.

If a thick, but relatively narrow lens of sand were surrounded by and buried in mud, and the whole later subjected to compaction by the weight of overlying sediments, it would seem to be inevitable that an anticlinal bulge would develop over the sand body as a result of differential compaction, the total settling of the mud on either side being greater than where the section is partly composed of sand. Questions which might be debatable are the degree of compaction suffered by the mud; the dimensions of the resulting anticlinal bulge; and the distance above the sand body through which the bulge might be noticeable. The latter would depend in part on how rapidly the compaction was completed. Sea-bottom processes tend to smooth out any irregularities that exist during the time of deposition and a bulge caused by settling could affect higher beds only if a noticeable part of the settling occurred after those beds had been deposited.

[1] Read before the Association at Los Angeles, March 17, 1937. Manuscript received, February 2, 1938.

[2] University of Cincinnati.

The problem assumes great practical significance because in eastern Kansas thick but narrow sand bodies embedded in the Cherokee shales, and representing both sand-filled stream or tidal channels and buried off-shore sand bars, hold rich accumulations of oil and gas. These oil and gas accumulations are dependent primarily on the distribution of the sand bodies rather than on ordinary "structure." Consequently they are difficult to find and difficult to follow after they have been discovered.

In the autumn of 1923 the writer became impressed with the idea that the so-called "shoestring" sand bodies of eastern Kansas might be represented at the surface by anticlinal bulges, due to differential compaction, large enough so that detailed structural mapping might make it possible to trace them beyond the limits of known production.[3] He thereupon undertook detailed structural mapping of several known "shoestring" oil pools which proved that most of them were expressed at the surface and that, in several instances, it was possible to trace them from territory already developed into territory not yet drilled.

The writer's first successful application of the method was in the extension early in 1924 of the "Bush City" channel-sand body south of Garnett, Anderson County, Kansas. This sand body is 30–50 feet thick, approximately 1,000–1,400 feet wide, and has since been developed as an oil pool continuously for more than 14 miles. By detailed structural mapping, the sand body was traced outward from the developed area and was picked up by the first wildcat well $3\frac{3}{4}$ miles ahead of production and not directly in the apparent trend. A second wildcat well halfway between the first and the proved area also was successful. The string has since proved productive between those points. A little later the position of the Sallyards-Madison sand-bar trend northward from the newly discovered Agard pool in Sec. 14, T. 24 S., R. 9 E., Greenwood County, to the Thrall pool in Sec. 32, T. 23 S., R. 10 E. was outlined for a client essentially as it has since been developed by drilling. This proved that even in areas where the sands were buried by as much as 2,000 feet of later sediments, recognizable effects of differential settling over them could be found at the surface by sufficiently detailed mapping.

In fact, it is probable that even at depths of 2,700–2,800 feet, the effects still persist, as is suggested by the following experience.

[3] The writer has since learned that at about the same time H. E. Crum in eastern Kansas was experimenting with the application of the principle of differential settling and Henry Ley was also using it in subsurface work because he had found that lenticular sands in the Cherokee shale commonly caused recognizable bulges in the overlying "Oswego lime." No claim of priority is here made because, so far as the writer knows, others may have been using the method still earlier.

From a detailed structural map of the Fox-Bush pool (one of the "Bartlesville" sand-bar pools, T. 29 S., R. 5 and 6 E., Butler County, Kansas) made by Marvin Lee and comprising approximately 58 square miles in and around the pool, a take-off was made with the regional dip eliminated. This was then given to one familiar with the theory under discussion, but who had no knowledge of the area covered, who was asked to outline with crayon the area which might be underlain by a thick sand body and to make locations for four test wells. It seems more than a coincidence that essentially all of the productive area of the Fox-Bush pool was included in one of the areas chosen as likely to be underlain by sand, and that two of the four locations for tests were in the heart of the Fox-Bush pool.

Subsequent experience justifies the statement that, in eastern Kansas, at least, probably every thick but narrow sand body is represented at the surface by an anticlinal bulge due to differential settling, but that not every structural feature which might be so interpreted represents a buried sand body. A variety of causes may produce features difficult or impossible to distinguish from bulges due to differential settling over a lens of sand, and bulges due to settling may be obscured and masked by structural features due to other causes. Hence gray hairs are likely to be the lot of the geologist who attempts to use the method. The method is far from fool-proof and experience and judgment as well as extremely careful mapping are essential for its successful application.

EXAMPLES OF STRUCTURES DEVELOPED BY DIFFERENTIAL SETTLING

To illustrate the structural effects attributed to differential settling over lenticular sand bodies buried in shale, two typical maps are shown, one from the shallow, east Kansas district, where the sand bodies of the channel type lie about 700 feet below the surface, and another from Greenwood County, farther west, where the sand is a buried offshore bar found at a depth between 1,900 and 2,100 feet.

Washburn College pool, Anderson County, Kansas.—This area was mapped at a time when the "Bush City" channel-sand pool was being extended toward it. A bulge suggestive of a sand body was found (Fig. 1) but its trend did not correspond with the expected trend of the Bush City pool, which later was found to pass by it approximately ½ mile to one side. Nevertheless, the area was leased and finally drilled on a location calculated to test the suspected sand body. The sand, containing oil, was found at the "Bartlesville" zone, approximately 100 feet below that of the "Bush City" pool. It has proved to be a

channel having a sand thickness of approximately 50 feet and a width of 1,000–1,300 feet. At the north end, the channel gives place to a bar

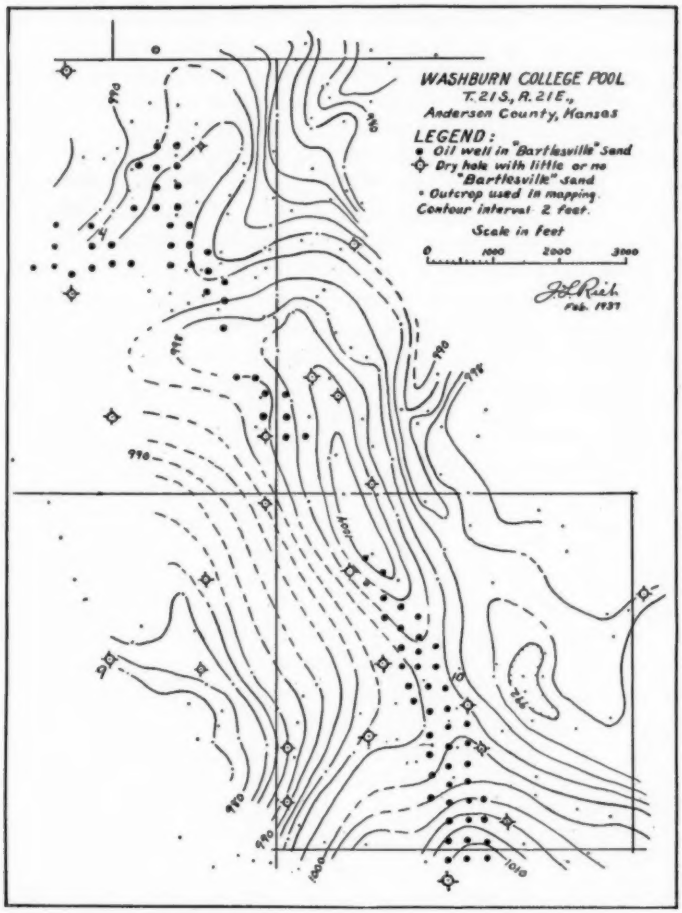


FIG. 1.—Part of Washburn College pool, Anderson County, Kansas, showing relation of production to structural bulge caused by settling over sand body. Dry holes have no sand at producing horizon.

deposit at a slightly higher level trending in a direction nearly at right angles to the channel and also recognizable in the surface structure. Owing to the greater sand thickness and greater oil yield of the

channel, its development has been pushed and the bar deposit has been only partly drilled.

After approximately a year of development on the original leases, during which time several unsuccessful wildcat wells were drilled by others in an attempt to extend the pool, leases became available on the indicated extension of the sand body on the south. These were taken up, and a test well was drilled $1\frac{3}{4}$ miles ahead of production which struck the channel sand and proved the deductions from the structural evidence to be correct.

The surface expression of the Washburn College channel-sand body (which lies at a depth of about 700 feet) is generally almost directly over the sand, although in some places, as shown on Figure 1, it is a little to one side. Along certain other "shoestring" sand bodies, however, what is taken to be the surface expression of the sand lies considerably to one side—so much so, in fact, that if one were to drill the top of the surface bulge he would miss the sand entirely. This is true of the central part of the Bush City shoestring to which reference has been made. If, however, in any particular area, the direction and approximate amount of offset can be established, allowance for it can readily be made.

Tiffany-Ellis trend.—Another example of the surface expression of a buried sand body is given in Figure 2, a map of a part of the Tiffany-Ellis trend in Secs. 8, 9, 16, 17, 21, 22, 27, 28, T. 23 S., R. 11 E., Greenwood County, Kansas. Figure 2 shows the structure as actually mapped. Figure 3 shows the same structure with a regional dip of 20 feet per mile toward N. 70° W. calculated out.

As is shown on the latter map, the structure of the region exhibits the typical rectilinear fault mosaic pattern described in an earlier paper,[4] on which is superimposed the smaller structure due to settling over the thick Bartlesville-sand body which crosses the area. At the north, around the southeast corner of Section 8, where the regional structure is relatively flat, the sand body shows as a distinct, symmetrical bulge in the surface structure. Farther south, in the southwest quarter, Section 16, where it crosses the steep dips of one of the rectilinear fault trends, the evidence of the sand body is not clearly distinguishable. Still farther south, in the south half of Section 21 and in Sections 27 and 28, the sand body lies on the western slope of a deep synclinal "hole." Here its surface expression over the central part of the sand body is obscured by the steep slope, but its western margin is clearly shown.

[4] John L. Rich, "Fault Block Nature of Kansas Structures Suggested by Elimination of Regional Dip," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 1540–43.

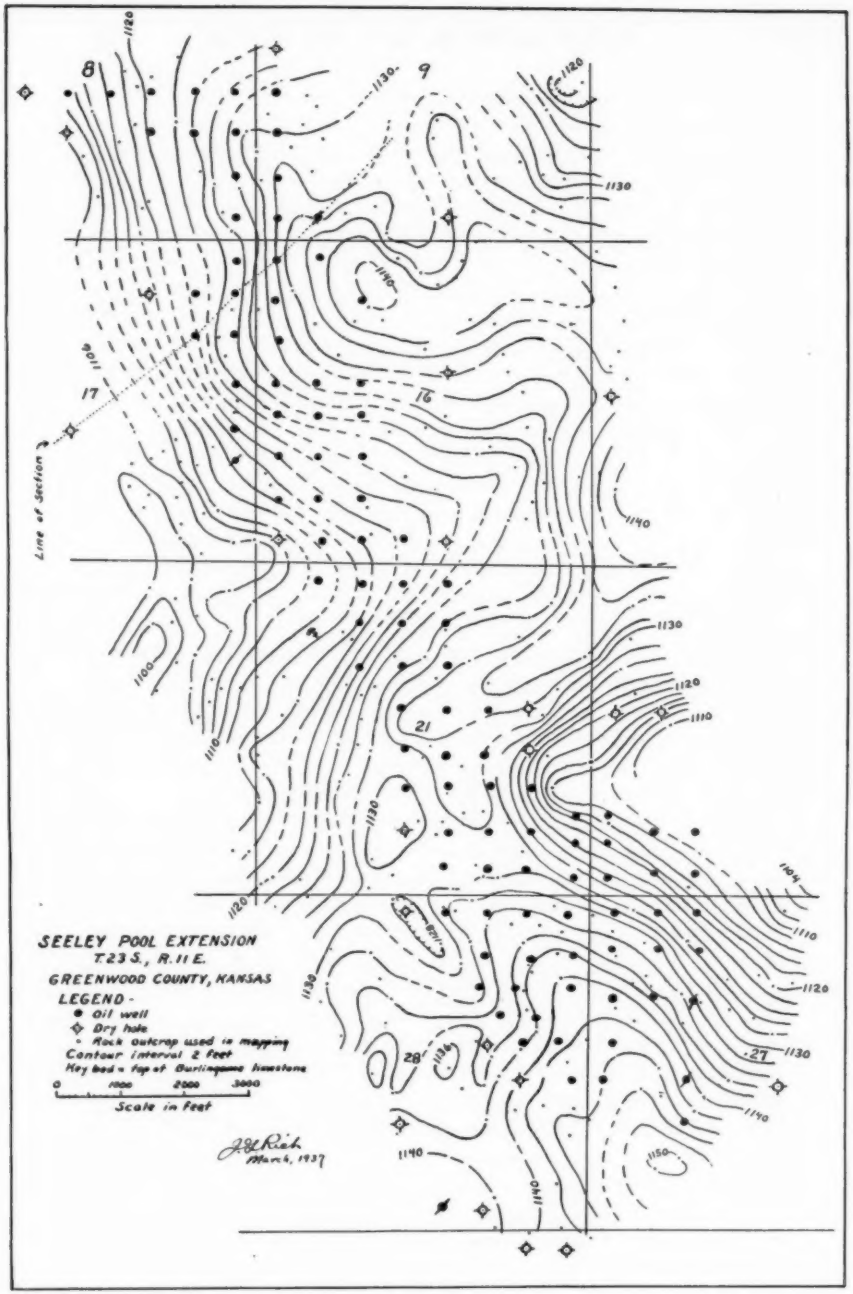


FIG. 2.—Seeley pool extension, Greenwood County, Kansas, showing structural expression of sand body. Dry holes miss producing sand.

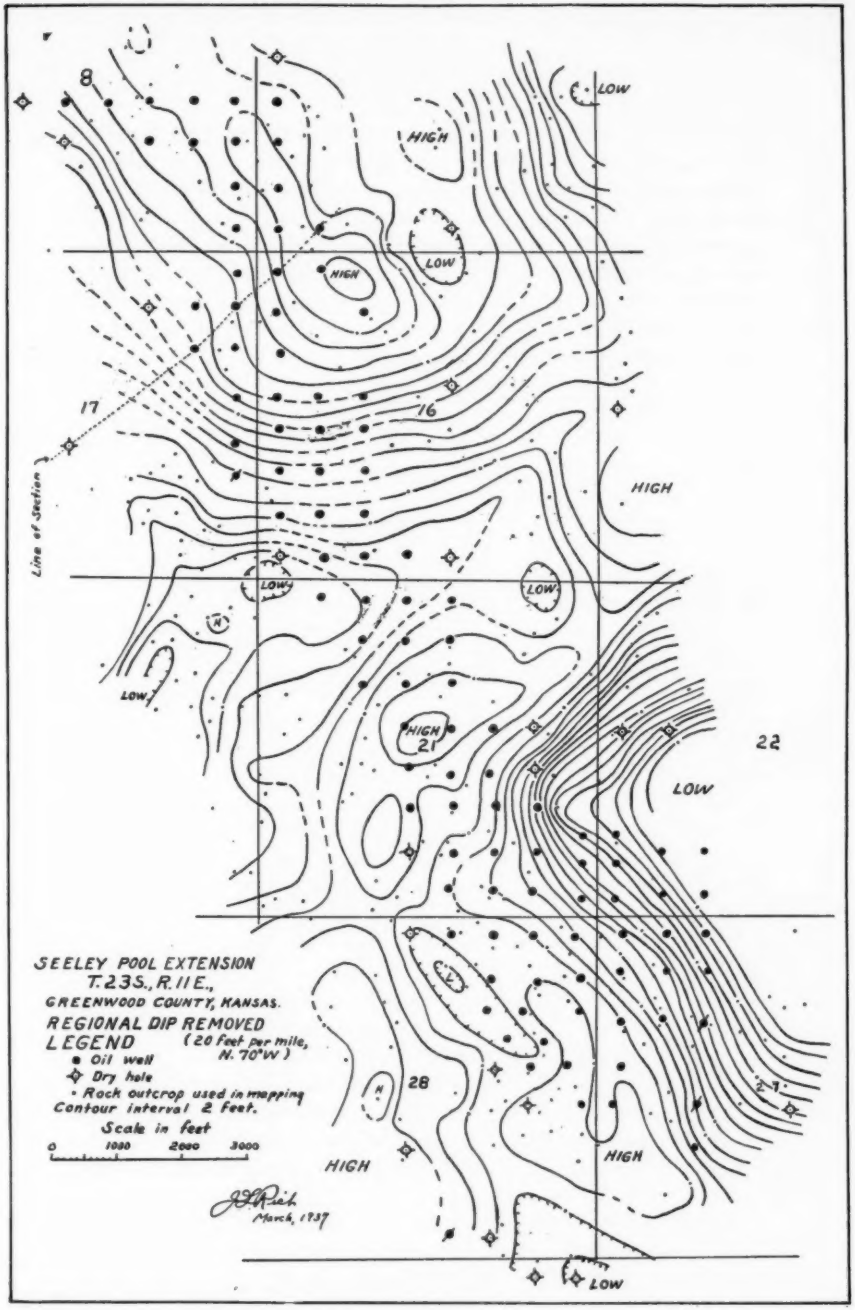


FIG. 3.—Seeley pool extension with regional dip removed. Structural expression of buried sand body is clearer than on unmodified structural map, but is still partly masked by more pronounced structural features due to causes other than differential settling.

A cross section of this sand body showing the relation of surface structural profile to sand thickness is given in Figure 4. It shows clearly the structural bulge over the sand, and also makes it possible to measure the amount of differential settling. The maximum sand thickness shown on this cross section is 87 feet, and the surface bulge measures approximately 12 feet in height. The depth to the top of the sand is approximately 1,900 feet. This indicates that even at a depth of 1,900 feet differential settling gives a bulge of approximately one tenth of the thickness of the sand body.

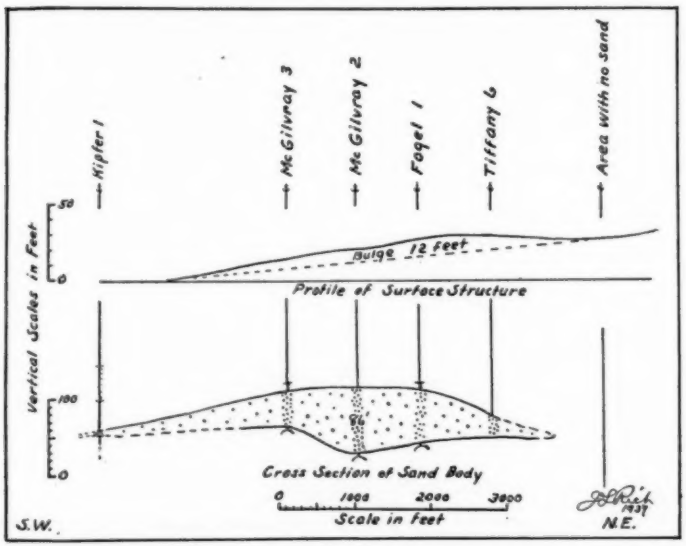


FIG. 4.—Cross section of north end of Seeley pool extension along line indicated on Figures 2 and 3, showing relative dimensions of sand body and of surface bulge interpreted as due to settling over it. (Note difference in vertical scale of two profiles.)

GENERAL CONSIDERATIONS

Even though every steep-sided, lenticular sand body—not too deeply buried—may be expressed at the surface by a structural bulge due to differential settling, it will not be possible to recognize all such bulges or to distinguish them from similar features caused by other things.

Essentials for success in utilizing the result of differential settling are: (1) even-bedded rocks at the surface with numerous well distributed outcrops; (2) not too many and preferably no horizons of lenticu-

lar sands either above or below the horizon where production is sought; (3) very detailed and accurate surface mapping.

With respect to the first of the above requirements, much of eastern Kansas is fortunately situated, for the beds over a considerable area, especially in Greenwood, Coffey, Lyon, and parts of Butler and Cowley counties are mainly marine and are remarkably even-bedded. Some parts of the section in eastern Kansas are unsuitable because of notable irregularity of deposition. One horizon that is particularly troublesome is that between the Iola and Stanton limestones where considerable changes in section within short distances laterally make attempts to distinguish bulges due to differential settling somewhat hazardous.

The Iola limestone and formations below it are very dependable for use in seeking sand bodies in the Cherokee shale because the bedding is notably regular and no important sandstones intervene in the section between the surface and the productive horizon.

Irregularities of deposition in any formation do not cause serious trouble unless they involve the beds at the surface or those close below, for a noticeable tendency has been found for such irregularities to be evened up and compensated in higher beds, so that if one is mapping surface rocks considerably above the horizon of irregularity, no trouble is likely to be encountered.

The second essential is that the section should not contain lenticular sands at too many horizons other than that at which production is being sought, for each sand lens will cause a bulge and the effect of no one of them will be conspicuous enough to be distinguishable. The ideal condition is that found in parts of the shallow fields of eastern Kansas where no sands are present in the section between the surface and the zone in which the productive lenticular sands occur. Farther west thick, and in some places lenticular, sandstones are found in the Stranger formation (Lawrence shale) below the Oread limestone. Consequently, when working west of the westward-dipping outcrop of these sandstones, one must always bear in mind that any indications of sand bodies that he finds may be due to these (generally unproductive) sands rather than to the sands which are being sought farther down in the section.

The third requisite is detailed mapping on a large scale and with a small contour interval. A scale which has been found satisfactory is 1,000 feet to the inch, with a 2-foot contour interval. This makes it possible to show the height and shape of the small structural features on which the application of the method depends, whereas a larger interval would generalize the shapes and might readily permit some

of the significant features to be overlooked. Even if outcrops are so few that considerable parts of the terrain are not covered adequately for a 2-foot interval, that interval still is desirable for such outcrops as are available, because a bulge may be clearly shown where it crosses the outcrop of a single key bed even if it can not be followed across the areas between outcrops.

CAUSES OF MISINTERPRETATION

One or another of three conditions is generally responsible for misinterpretations and lack of success in finding sand bodies where the surface evidence indicates they might be present.

The first is where unproductive lenticular sands are present in the section either above or below the pay zone. In a wildcat area no way is known of distinguishing between bulges caused by such sands and those caused by the productive sands being sought. Prospecting is consequently more hazardous in such areas. Where "stray" sands are present the method can still be used to good advantage in tracing out a known productive sand into undrilled territory.

A sand not at the pay horizon should cause no difficulty if it is uniform in thickness or if its changes in thickness are gradual.

The second confusing factor is the presence of small structures due to something other than settling over sand bodies. These may be due to a variety of causes. In eastern Kansas one of the most troublesome conditions seems to be due to settling over irregularities in the top of the "Mississippi lime," which was a land surface with considerable local relief before its burial under the shales of the Cherokee (Pennsylvanian) sea in which lie the productive lenticular sand bodies.

Small bulges in synclinal areas which might be interpreted as caused by buried sand bodies may really be due to buckling of the surface beds as an accommodation to the down-bending in the syncline.

A third cause of difficulties is the offsetting of the surface bulge to one side of the buried sand. This has been observed in several places and its cause is not fully understood. The offsetting may be so great that a well on the top of the bulge would miss the sand altogether. Offsetting seems to be most conspicuous where the rocks have considerable local dip and the sand trend is parallel to the strike. The surface bulge is generally, if not without exception, displaced up-dip from the sand body. In part, the displacement may be due to the fact that a bulge so situated may appear only as a flattening of the dip, and this is noticeable over the up-dip edge of the sand rather than over the middle. Another factor may be lateral slippage of beds to accommo-

date themselves to sinking into structural "lows," but the amount of offsetting in some places seems too great to be due to this cause alone.

In discussion at the Los Angeles meeting A. I. Levorsen expressed doubt as to whether the bulges here described are really due to differential compaction rather than to some effect of the lenticular sands on the folding of the region. This possibility had been considered previously and rejected as an explanation of the bulges for the following reasons. 1. The region under discussion is not folded in the ordinary sense of having its structures produced by lateral compression. The structures seem to be due mainly to differential up-and-down movements of blocks of the basement complex along fracture lines, as is revealed by their pattern when detailed mapping is done and regional dip eliminated. 2. The bulges can be traced across country, crossing the "structures" at all angles. 3. The bulges follow the curves of the sand bodies.

LIMITING DEPTH AND ITS IMPLICATIONS

From the results of the work in Greenwood County, Kansas, where the offshore-bar sands attain a thickness ranging from 75 to 100 feet, it is evident that the surface expression of differential compaction over the bars can be recognized where they are more than 2,000 feet beneath the surface, and possibly as much as 2,800 feet, as in the Fox-Bush field of Butler County.

That the effects of compaction should appear in rocks 2,000 feet above the sands must mean that compaction was slow enough so that an appreciable part of it was not completed until after 2,000 feet of rock had been deposited. This is a somewhat surprising conclusion, but perhaps should not be so, for the work of Hedberg[5] and Athy[6] indicates that compaction is to a considerable degree dependent upon the weight of the overlying rocks and consequently continues throughout and possibly for a long time after the period of deposition.

[5] H. D. Hedberg, "The Effect of Gravitational Compaction on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1035–72.

[6] L. F. Athy, "Density, Porosity, and Compaction of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 1–24.
Idem, "Compaction and Its Effect on Local Structure," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 811–23.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 834-851, 1 FIG.

CRITERIA FOR DETERMINING THE TIME OF ACCUMULATION UNDER SPECIAL CIRCUMSTANCES[1]

STANLEY C. HEROLD[2]
Glendale, California

ABSTRACT

The problem of determining the time of accumulation is related closely to that of determining a sequence of geological events. It, in fact, includes the one of determining the time of unconformity. Thus far, then, the criteria of the two problems are identical, and the determination is dependent upon geological observations in the region being given consideration. Major and minor unconformities have distinct significances with respect to migration and accumulation. But the determination of the time of accumulation is also dependent upon criteria which are mechanical in nature, and which are only to be observed during drilling and production.

A diagram entitled "Restricted Sequence of Geological Events" is used as a basis of the present treatment of the subject. The axis of time is divided into nine periods, each of which has particular significance with respect to the problem. This diagram may prove to be deficient for many regions. It is designed to cover the general problem only in so far as we find it necessary for the consideration of accumulations under the special circumstances considered here.

Accumulations are classified according to two categories. The first relates to such as are found in porous strata of Cenozoic age, and the second relates to others in porous strata of Paleozoic age. Which of the two is appropriate for strata of Mesozoic age is at present unknown because of the lack of sufficient data.

Accumulations of the second category are found from north Texas to the province of Ontario, where they lie in strata ranging in age from Ordovician to Permian. Migration and accumulation took place before the truncation by erosion or the subsidence of the petroliferous strata along their upturned edges around the area in which the accumulations are situated, and any subsequent elevation or subsidence, folding, warping, or tilting of the accumulations was not accompanied by a lateral shifting of the pools to accommodate new structural conditions. Accumulations are, therefore, frequently found on a flank of an otherwise barren anticline, on a terrace, or in a syncline. Occurrences of this sort played an important part in early discussions (1865–1885) relating to the anticlinal theory of accumulation.

INTRODUCTION

The problem of determining the time of the accumulation of oil and gas within the porous strata where they are now found by the drill is closely related to that of determining the sequence of geological events within the area containing the accumulation at depth. The latter problem, however, at least in so far as geological time is concerned, is broader in scope, for the periods of time involved in the accumulation of oil and gas, and in their retention in place until the present day, are necessarily short in total duration, as compared with all geological time involved in the complete history of all igneous and sedimentary rocks which are directly and indirectly associated with the sedimentaries of the accumulations.

[1] Presented by title before the Association at New Orleans, March 18, 1938. Manuscript received, February 24, 1938.

[2] Consulting geologist.

The time of accumulation is not alone in this relation to the sequence of geological events, inasmuch as the time of unconformity bears a similar position with respect to it.

Long ago the problem of determining the time of unconformity confronted geologists. That one they solved as to criteria and interpretation. We now face a similar problem. Already our criteria can be set forth clearly, for they include in fact the unconformities of the region. And to these must be added other criteria revealed by the behavior of wells and pools on production and development in the oil and gas fields within the region. If the proper interpretations seem difficult in their making, we may hope that it is because of their novelty. Where the older geologists recognized the fact that the study of an unconformity can best be confined to one region at a time, we should assume that the same is true for us. Where they treated separately the several unconformities in one region, we should treat separately our accumulations. As they frequently noted a relation between particular unconformities in contiguous or non-contiguous regions, we can in a broad way do likewise. It is in that portion of proper interpretations which is dependent upon or influenced by the behavior of wells that difficulties may for a time arise. The required observations in oil and gas fields may not have been made by the geologists. But this situation is, of course, easily remedied.

Herein it is found necessary to treat of the general case in accumulation in order that the special circumstances may be properly differentiated. In other words, we follow in a general way the history of oil and gas accumulations, whether they be in Paleozoic or Cenozoic strata, in order that we may note particularly the criteria offered by those in the Paleozoic strata.

RESTRICTED SEQUENCE OF GEOLOGICAL EVENTS

The migration and accumulation of oil and gas are taken jointly as a geological event equal in the order of importance to any other geological event which concerns the particular strata. The data of events, to serve as criteria, must point directly and unmistakably to one or more periods for accumulation in relation to the other periods. For any particular region whatever, a sequence of geological events can be charted graphically along a horizontal line which represents geologic time. Naturally a considerable amount of field study is required to give accuracy to such a record. All minor events can not be registered, and they need not be, inasmuch as our problem in its solution does not require them. It is obvious, therefore, that any chart we may construct is one showing a restricted sequence of events. A

chart of this nature is shown in the accompanying diagram (Fig. 1). For convenience of reference the successive periods of time are designated by letters below the time line. Brief descriptions of the period appear above this line. These require elaboration.

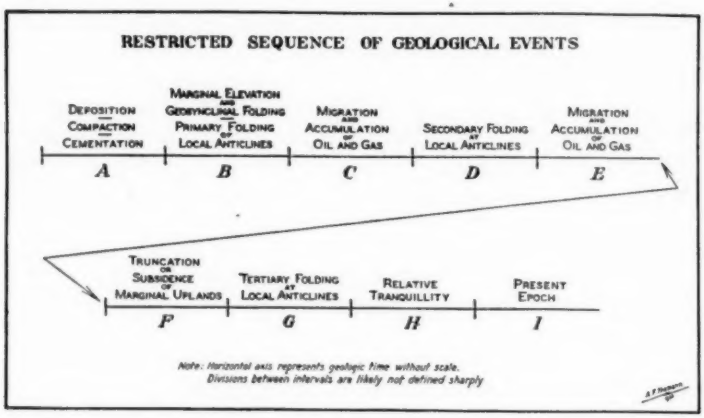


FIG. 1

A. DEPOSITION, COMPACTION, AND CEMENTATION

All events preceding this one, which begins the history of sedimentary rocks in the region, are ignored. This period, of course, requires the submergence of an extensive area that is bordered by uplands undergoing erosion. Climatic conditions are such that the weathered material is transported to the submerged area. Sediment is continually deposited in stratified form. The weight of the upper strata tends to compact or consolidate the lower strata. In time these are hardened by cementation. They have become sandstones, shaly sandstones, sandy shales, shales, or other appropriately named clastic rocks.

We are considering a series of strata making up a formation. For each individual stratum it would be proper to specify three separate periods in the place of the one here shown, namely, one each for deposition, compaction, and cementation. In a series, these are imagined to have taken place progressively from the lowermost to the uppermost strata.

It is not to be inferred that compaction and cementation are confined absolutely to this period. These processes most likely continue through much of the subsequent history of the strata because of the

continued effects of the superimposed mass, subsequent folding, and the prolonged infiltration of mineral-bearing solutions.

B. MARGINAL ELEVATION AND GEOSYNCLINAL FOLDING. PRIMARY FOLDING OF LOCAL ANTICLINES

This period is designated in accordance with the fact that most of our anticlines productive of oil and gas are located in geosynclinal basins. The marginal territory which has been raised may or may not include, or be a portion of, those uplands which furnished the materials for deposition in the preceding period. The elevated area at its edge has specifically affected the deposited strata, for an area, as a rim, has been raised with the result that a geosyncline has been formed. The forces which caused the elevation are imagined to have had components that produced the primary folding of anticlines within the geosynclinal basin. In virtue of this situation, the strata at depth on the anticlines are exposed in outcrops at relatively high altitudes and at relatively high dip angles along the front of the elevated area.

In mentioning anticlines it is not the intention to exclude other structural traps which are capable of holding accumulated oil and gas. It is assumed that the closed anticline, or dome, is the shape of structure wherein accumulation of oil and gas may be accounted for in the most explicit manner. With this in mind, the discussion will be confined to anticlines.

Primary folding of anticlines, while being associated with major tectonic movements, may or may not in itself be a major folding. Frequently there is evidence to the effect that the primary folding was less intense than subsequent secondary or tertiary folding. Considerations herein will not be dependent upon these facts.

Primary faulting may accompany the primary folding of the period. This depends upon the direction and intensity of the component forces and upon the competency of the strata. The latter, in turn, depends upon the nature of the rock comprising the strata and the load superimposed upon them.

Movement in this period of elevation and folding may have been continuous or intermittent. In fact, there may have been two or more periods between which events of another nature took place, but now they appear to be separately indistinguishable.

C. MIGRATION AND ACCUMULATION OF OIL AND GAS

Oil and gas were formed at some time after the beginning of A and before the beginning of C. The fact that accumulation has taken

place requires the assumption that sufficient time has elapsed preceding C for the generation of these hydrocarbon fluids under whatever favorable conditions may have been required in order that they come into existence. Source beds, most likely massive shales, lay in contact with such porous and permeable strata as sandstones. Compaction subsequent to the generation of the hydrocarbons has squeezed the fluids into the adjoining porous strata. The latter are, as we know, more competent to resist compaction. There was, then, a short "transverse" migration, so to speak, across bedding planes of the strata. Thereupon the fluids are in the carrier beds, and they are, of course, subject to "lateral" migration in a direction parallel to the bedding planes of the strata. Impermeable strata immediately overlying and underlying the permeable carrier beds tend to prevent further transverse migration.

Faults can permit transverse migration; they can also prevent continued lateral migration.

Carrier beds—those strata in which migration takes place—are most frequently some of the very beds in which accumulation takes place in local favorable structures. In fact, accumulation may be considered as arrested migration, and arrested migration may be due to the effects of gravity, to the faulting of strata, or to a lateral change in lithology from permeable to less permeable rock within the carrier beds themselves.

Carrier beds are often composite in texture. The individual strata vary in porosity and permeability from bottom to top according to the materials available and the conditions of deposition prevailing from time to time when they were laid down. The more permeable strata are selectively the more proficient carriers. Pressures under which the fluids exist are often sufficient to cause transverse migration from the more permeable to the less permeable layers. But impermeable strata between permeable ones prevent transverse migration except at places where they were sufficiently brittle to become shattered when folded. Thus migration must often be confined to fewer strata than accumulation, particularly on narrow anticlinal domes with steep flanks and of considerable closure.

All porous and permeable sedimentary formations contain fluid. The truth of this statement is obvious. If they contained nothing, a vacuum would exist within them, and this is contrary to the nature of things. If they contained solids, they would not be porous and permeable. Then they contain some kind of gas, some kind of liquid, or both. Near their outcrops it may be imagined that some such strata contain air only. It is not likely that air would extend to great dis-

tances down the dip from the outcrops, for either the oxygen would disappear, leaving nitrogen, or else the air would be replaced by carbon dioxide. Certainly instances of both nitrogen and carbon dioxide have been noted. Numerous cases of dry methane gas, often diluted somewhat with nitrogen, have also been noted. Deposits of carbon dioxide and dry methane gas have been turned to production, as we know.

Fresh water in such strata is known to be common. Again, however, it is not likely that fresh water can extend ordinarily to great distances down the dip from the outcrops, for either it will pick up soluble salts from the rocks or it will be contaminated with saline waters already present in them. With the continued production of saline water at wells down the regional dip, the gradual change from saline to fresh water has been noted frequently.

Our present interest is concerned with saline waters, liquid hydrocarbons, and gaseous hydrocarbons, all being of a complex nature, the first because of dissolved inorganic salts and the last two because of their molecular constituents which include solids, liquids, and gases.

Carrier beds, so long as they functioned as such, were always fully saturated with water at the time of migration and accumulation. It can not be far from the truth to say that the water was always saline water—connate saline water which was entrapped with the sediments when their rock particles were deposited. This water became the agent of lateral migration. As it moved through the carrier beds so were the oil and gas moved, oil in the form of globules and gas in the form of bubbles, each coalescing into larger masses as it progressed slowly along its path.

Water moves downward in seeking a lower level. It moves downward with the regional dip of all geosynclines. If it moves upward over a local anticline within the geosyncline, it does so to attain a lower level on the other side of the anticline. Water does not move upward, opposed to the regional dip, for if it should do so we would have numerous saline springs at outcrops. Water, in fact, enters porous and permeable strata at their outcrops, particularly where these outcrops are crossed by stream beds. Some lateral spreading takes place immediately below the outcrops in the adjustment of level; otherwise there is no lateral movement along the strike of beds except in those possible lateral components induced by a lithological heterogeneity within the beds.

The migration of oil and gas is also downward with the regional dip of the geosyncline. The free gas seeks the hanging wall, and the water the footwall, of the carrier beds, with the oil seeking a middle position.

In a hollow container water can not force gas and oil downward, for the fluids separate according to their specific gravities. In a porous and permeable medium, however, water has no difficulty in forcing the lighter fluids downward. In fact, water will force gas and oil vertically downward in a capillary tube, and porous and permeable formations act as bundles of capillary tubes.

Within carrier beds the gas and oil do not move in any direction if the water in these beds is not moving, because of the effects of surface tension. Consequently oil and gas can not move upward, opposed to the water. And only by virtue of some movement do gas, oil, and water tend to separate according to their respective specific gravities.

Oil and gas migrate downward in slugs. Larger masses of water are nevertheless by-passing these slugs, so that the bulk of the water in a formation is moving more rapidly than these fluids. Where the carrier beds pass over an anticlinal structure the lighter fluids escape to the crest; further migration is arrested, and an accumulation forms. The migrating water thereafter must seek a by-pass along the lower contours of the structure. Pools of oil and gas are thus surrounded by water, and they remain so as long as the pool exists on the crest of the anticline.

If, because of a lack of continued supply at the outcrops, the water in the formations becomes depleted, oil previously accumulated on structurally high positions will descend into adjoining local synclinal areas, leaving only free gas at low pressures in the earlier position. A few synclinal occurrences of oil undoubtedly due to this cause have been noted. Occurrences due to other causes are to be considered hereafter.

Pressures under which gas and oil exist within an accumulation are fundamentally due to the hydrostatic column of water in its extension upward, along the carrier beds to their outcrops. To this rule there are no conceivable exceptions. In most of our presently developed oil fields of the United States and elsewhere the pressures are still of the same nature, although in the Mid-Continent and Eastern regions of this country they have undergone a modification in geologic time since accumulation. In these the action of the hydrostatic column of water has been stopped.

D. SECONDARY FOLDING AT LOCAL ANTICLINES

Field observations frequently indicate minor folds along the axis or flanks of anticlines. It is not proper to imagine that in every case these minor folds were formed in a period subsequent to that of major

folding, for they may indeed be merely the less intense features which were formed simultaneously with the larger fold. With secondary folding there should be included such particular types of movement as the longitudinal or transverse tilting of the anticlines without other deformation of structure, and also that deformation described simply as a warping of previously folded strata.

Minor secondary folding produces structural features with minor axes which did not exist previously. Tilting is the effect of unequal elevation or subsidence on opposite sides of a structure. It is accompanied by a lateral shift in the position of the preëxisting axis. Warping is an increase or decrease in the intensity of a structural feature without a lateral shift in the position of the preëxisting axis.

The period A pertained to the strata directly related to the origin of hydrocarbon fluids and to their subsequent migration and accumulation. The present period, D, on the other hand pertains to the same strata and all younger ones superimposed upon them. The latter contain the evidence of secondary folding or warping in any minor unconformities which may be present. They also contain the evidence of tilting without deformation in any alteration of the thickness of strata in some direction.

Secondary faulting, as an accompaniment of secondary folding, is often observed. As in the case of primary faulting with primary folding, such secondary faulting indicates conditions wherein the applied forces exceeded the elastic limit of the strata.

Mention has already been made of the fact that secondary folding may indeed be either a major or minor folding in comparison with primary folding.

Like the primary folding, the secondary folding of anticlines may have been either continuous or intermittent.

A further shattering of brittle impermeable strata separating porous beds with an accumulation of oil and gas is possible during secondary folding. Beds on an anticline naturally have a greater degree of freedom for movement. It is doubtful that the same beds in local synclines can be shattered. Certainly the synclinal folds between anticlines are most frequently not as sharp as those on the intervening anticlines. Downward movement of the beds in synclines is limited to a possible compaction of underlying formations. Furthermore, the superimposed load on corresponding beds is greater in synclines than in anticlines. Both of these factors tend to localize any shattering to anticlinal areas.

Secondary folding at local anticlines may, of course, be absent in many regions, or at least there may be no evidence of it today. If this

is true, the period of time specifying such a folding on the chart of geological events must be omitted, and the adjoining periods of migration and accumulation become in fact one and the same period.

Anticlinal areas during this period may have been subjected to elevation or subsidence without deformation of the structure itself. Subsidence often resulted in a resubmergence with the deposition of still younger beds.

E. MIGRATION AND ACCUMULATION OF OIL AND GAS

Migration and accumulation of oil and gas may not have taken place during the period C, preceding that of D. However, sufficient geological time presumably had elapsed since the period A for the generation and transverse migration of the hydrocarbon fluids to have occurred. But if such a presumption is improper, it is certain that both lateral migration and accumulation had been accomplished by the end of the period E, before the period F.

If migration and accumulation took place in C, it is probable that they did not cease entirely by the end of this period, but continued, at least to some extent, during D and E. In other words, the pool of oil and gas which had formed by the end of the period C was augmented somewhat during D and E.

Accumulation should be looked upon as a process of concentration. In most respects the accumulation of oil and gas resembles the concentration of gold particles. The "minerals" of tenuous distribution are picked up by moving water and deposited in suitable traps provided by nature. Whereas gold particles are concentrated by means of their greater density, oil and gas are concentrated by means of their lesser density. Both processes probably continue as long as the requisite conditions prevail, namely, those of distributed particles, moving water, and trap space.

With the lack of trap space there can be no concentration, either of oil and gas or of gold. The particles after transportion are as tenuously distributed as they were before transportation. Undoubtedly much oil and gas has thus escaped us. They are lost in so far as economic recovery is concerned.

An accumulation of oil and gas throughout its existence has been subject to mechanical readjustments. The areal extent of the pool increased with the continued collection of oil and gas, and it increased with any decrease of the pressure exerted by the surrounding water because of the liberation of more gas from solution and the expansion of all gas in the free state. It decreased with any leakage of oil and gas to the overlying and underlying beds, and decreased with any increase of the pressure exerted by the surrounding water.

During the period D the oil and gas bearing beds at their outcrops may have changed their height by elevation or subsidence, or they may have suffered from erosion. The height of the water column in the beds would have changed accordingly. On the other hand, during the same period the anticline changed its shape. It may also have undergone elevation or subsidence. In any case, it is clear that adjustments to meet the conditions were necessary. If further shattering of brittle impermeable beds occurred in the period D, the pool may have increased in its vertical extent. Adjoining beds previously containing water may now have become saturated with oil and gas.

There is evidence of upward vertical leakage in many fields. Often the uppermost productive sands contain only gas. Shattering would naturally be most intense on the crest of the anticline, and as a consequence the gas caps of the underlying sands had the best opportunity for supplying fluid to the overlying sands. Either the settling of the formations, with its resulting compaction, shut off long-continued leakage, or the shattering was such that the cracks permitted the leakage of gas, but not that of oil. That both the shut-off and the discrimination of fluids took place is very probable. Accordingly, then, all free gas from lower gas caps escaped into the uppermost sands, no oil from the lower sands escaped into the uppermost sands, and the free gas encountered today in gas caps within the lower sands is new gas, having become separated from the oil since the shut-off.

The upward leakage of oil in other instances is clearly indicated. If with two closely situated anticlines we find an uppermost sand saturated with oil on one and identically the same sand saturated with water on the other, it seems we have evidence of the leakage of oil on the first anticline with the absence of such leakage on the second. In any event, the leakage of gas and oil into upper sands must decrease the areal extent of the pools in the lower sands.

Leakage of oil and gas into lower sands is suspected in some fields, although the indications are not yet as positive as in the case of leakage into upper sands. The data are naturally more difficult to obtain, inasmuch as wells must pass through the uppermost sands and they frequently do not reach or pass through the lowermost sands.

Mechanical adjustments at the edge of a pool of oil and gas can not be expected to be the same at all points around the pool. The effects of surface tension will prevent as complete a readjustment in a fine-grained sand as it does in a coarse-grained sand immediately adjoining it. Again, the effects of surface tension will prevent as complete a readjustment on a dip-slope of low angle as it does on one of high angle, on the assumption that the sands of the two slopes are

lithologically identical. Bubbles of free gas distributed throughout the oil, both fluids being within a sandstone, bring these effects of surface tension into play. Small differentials in pressures within the various parts of a homogeneous sand can persist in virtue of the presence of the bubbles. Equilibrium is attained as a balance between forces which include these differentials. As a result, we often find pools eccentrically located with respect to the structure. The edge of the pool extends farther down on flanks and plunges of low angle than it does on flanks of high angle. There are more bubbles within oil for a vertical rise of, say, 100 feet in a stratum of 20 degrees dip than for the same rise in a stratum of 70 degrees.

In the case of elevation or subsidence of anticlinal areas, during the period D, without deformation of the structure, it is obvious that no mechanical readjustment of the pool takes place during the period E.

Hydrocarbon fluids are sensitive to changes in temperature and pressure, and these fluids, of course, encounter such changes during migration and after accumulation. For every conceivable combination of temperature and pressure likely to exist underground the fluids have a normal state of equilibrium, and any change results in a disturbance of this equilibrium. By chemical readjustment they proceed to acquire a new state of equilibrium in accordance with the new conditions. The readjustment is, in fact, physico-chemical as to liquid and gaseous phases without molecular alteration, and strictly chemical as to molecular alteration itself. The physical properties of oil and gas, including specific gravity, viscosity, and surface tension, vary in a field as to strata and position on the structure, and this variation is accentuated by secondary folding at the anticlines.

F. TRUNCATION OR SUBSIDENCE OF MARGINAL UPLANDS

Marginal elevation and geosynclinal folding with the primary folding of local anticlines ascribed to the period B are highly important geological events in connection with the migration and accumulation of oil and gas. Without them there could not have existed the events of the periods C and E. The geological events second in importance only to those of B are those of the period F.

It must, of course, have been true that some amount of truncation by erosion over the uplands had begun immediately after their elevation, and that this erosion had continued throughout the periods C, D, and E. Eroded rock particles transported off the high land were deposited elsewhere on submerged lands. They, in fact, became the

younger strata over the anticlinal areas in the geosynclinal basin. Obviously the latter areas were submerged, else there would not have been such younger strata deposited on them. Not until the period F, however, had the truncation proceeded sufficiently, either to approach nearly, or to surpass, a definite crisis in height for the exposed outcrops of the porous and permeable strata which served in migration and accumulation. These strata, it will be recalled, had also been elevated so as to lie in a flanking position with respect to the marginal uplands.

The crisis in height for the outcrops is a matter of height for the column of water within the strata. Upon this column of water depends the pressure exerted at the edge of the accumulated pool of oil and gas by the water immediately surrounding it, and likewise upon it depends the pressure existing within the pool itself. With a decrease in the head of water caused by erosion, more free gas escaped from the oil, and all gas originally and newly in a free state expanded. While erosion continued, more and more bubbles of free gas came into existence throughout the mass of oil. Thus the forces of surface tension were gradually increased in their total effect. All the bubbles of gas within the pool offer a resistance to the movement of the fluids in and around the pool. Their effect in causing the eccentricity of a pool with respect to its location on a structure has been noted heretofore in consideration of the period D.

If the pressure of the column of water is sufficiently great, the differential between this pressure and that of the atmosphere—a differential established when the pool is tapped by a well—is itself sufficiently great to exceed the resistance of the bubbles. They can not restrain the pushing of the edge water against the pool, and all fluids move toward the well when the latter is permitted to flow. But if, on the other hand, the pressure of the column of water is not sufficiently great, the differential pressure so established is not able to exceed the resistance of the bubbles. They then restrain the pushing of the edge water against the pool, and only the oil and gas, because of the expansion of the latter, move toward the well.

During the course of truncation at the outcrops, then, the critical height is reached when the specified differentials change from competent to incompetent ones.

It is clear that any subsidence of marginal uplands will have the same result. It is immaterial whether the subsidence has been intermittent or gradual since the marginal elevation in the period B, or sudden during the period F itself. Often there is evidence of both subsidence and truncation in our oil regions. A subsidence which

causes resubmergence permits major unconformities by the subsequent deposition of younger strata. These major unconformities, as we know, are not uncommon in marginal areas.

The critical height by truncation or subsidence has not been exceeded in regions wherein the strata directly concerned with migration and accumulation were deposited after the Mesozoic Era, and it has been exceeded in regions wherein those strata were deposited before that era. This places accumulations in two categories best illustrated by those in Cenozoic and Paleozoic strata, respectively. Exposures of Cenozoic petroliferous strata are at relatively high altitudes. Accumulations within these strata always have been, and still are, subject to mechanical adjustments in accordance with any minor folding, tilting, or warping of local anticlines since the period B. Exposures of Paleozoic petroliferous strata are either at relatively low altitudes, or they do not exist at all. In the latter case the previously upturned edges of the strata lie at depth, covered by younger strata with a high angular unconformity. It is clear that the fields of the Pacific and Gulf coasts fall in the first category, while those of the Mid-Continent and Eastern regions fall in the second one.

As to pools in Mesozoic strata there are as yet insufficient data to warrant a general statement. In the Salt Creek Field of Wyoming, for example, it appears that the First Wall Creek Sand belongs to the first category, while the Second Wall Creek Sand belongs to the second one.

Exceptional fields with regard to the categories are, of course, possible. None has been noted to date. In California a subsidence during the period F, permitting deposition with a major unconformity, may have switched an accumulation from the first to the second category. If it did so, a subsequent elevation corrected the situation by raising the unconformable strata to a position above sea level where we now find them.

With the possibility of exceptional cases in mind we should in each field take note of the following features which will distinguish Paleozoic conditions in contrast to Cenozoic conditions:

1. At wells the productivity indices are of the order of 3 to 10 barrels of oil per pound per ***hour*** (Oklahoma City) instead of indices of the order of $\frac{1}{4}$ to 10 barrels per pound per *day* (Santa Fe Springs).

2. As field production continues, there is conclusive evidence that the edge water does not encroach upon the pool of oil and gas (Cushing), in contrast to conclusive evidence to the contrary (Kettleman Hills).

3. With technical success, by means of input and output wells, the operators are forcing oil production with water (Pennsylvania) and with gas (Oklahoma). Without technical success, the forced drive has been tried in some fields (California).

Each of these items is sufficient in itself. The first can be applied to a newly discovered field, the second to one about fully developed, and the third to another in its later stages of exploitation.

G. TERTIARY FOLDING AT LOCAL ANTICLINES

In fields of the first category any tertiary folding after the period F can only be distinguished from secondary folding before F upon the basis of geological studies in the region. The evidence is in the detection of minor unconformities in the anticlinal areas, due to folding, tilting, or warping, within strata younger than those which overlie with a high angular unconformity the petroliferous strata bordering the marginal uplands. In fields of the second category the distinction between such secondary and tertiary folding need not rest upon this geological evidence alone. After the period F there can be no migration and accumulation, nor can there be any mechanical adjustment of the pool in its position within the strata to accommodate the tertiary folding of the period G. The bubbles of gas by virtue of the events in F have securely locked the oil in place within the strata. It is because of this fact that these fields have acquired the characteristics previously ascribed to them; namely, the features pertaining to productivity indices, edge water encroachment, and successful forced drive.

With respect to fields of the second category the following facts are certain:

a. Migration and accumulation took place after the period B and before the period F.

b. Oil and gas in the accumulated pools remained stationary within the strata while the latter moved during the period G, so that oil and gas are now found where the crests of the anticlines were previously located, and not necessarily where the crests of the anticlines are now located.

As a consequence the pools, as developed today, are often

1. Very eccentrically located as to structure,
2. Off the crest and on the flanks,
3. On terraces, and
4. In synclines which adjoin anticlinal structures.

As to synclinal occurrences of oil, we find that wells drilled beyond

the edge of the pool encounter water. In this they differ from the previously mentioned possible synclinal occurrences in fields of the first category, inasmuch as the latter have no water surrounding them. Synclinal areas in regions of the second category can not be condemned hastily simply because they are synclinal.

In some regions having Paleozoic characteristics there appears to have been no tertiary folding at local anticlines, while in others, merely an elevation or a subsidence, without deformation by folding, tilting, or warping, is in evidence for the period G. These circumstances do not alter the fact that accumulation took place before, and not after, the period F. The accumulated pool remains concentrically located with respect to the structure as it lay during the period E, except for the previously discussed minor eccentricity which may have resulted from the events of the period D.

Minor tertiary faulting may accompany the folding of this period. The effect of faults which are such as to permit leakage now differs in accumulations of the two categories. In the first, the porous strata suffering leakage are replenished in time within the vicinity of the faults by an inward movement of the oil and gas in virtue of the pressure of the water surrounding the pool. But on the contrary, in the second category, the strata are not thus replenished. Leakage reduces the saturation of the inflicted strata in the vicinity of the fault by the amount of oil and gas entering the overlying or underlying strata beyond the impermeable confines of the previous accumulation.

H AND I. RELATIVE TRANQUILLITY AND PRESENT EPOCH

Little need be said regarding these two periods of time. Some geologists believe that the crust of the earth never has been and is not now quiet. For them perhaps the periods here designated as G, H, and I are in reality but one period. The intention here is to convey the idea that since the beginning of G no event having an effect contrary to those of F has occurred, and that since the beginning of H the effect of any event has been very slight and, therefore, is negligible at the present time.

SUMMARY AND CONCLUSIONS

In introducing criteria of a mechanical nature for determining the time of accummulation under special circumstances, wherein the truncation or the subsidence of petroliferous strata along preëxisting marginal uplands has lowered the pressure exerted by the water sur-

rounding the pool to such extent that bubbles of free gas have, by their surface tension effects, locked the oil—and incidentally themselves—firmly in place within the pores of the strata, it has been necessary to include the criteria of a geological nature which in fact apply to accumulations under all circumstances. This is, it seems, a sufficient reason for presenting the accompanying diagram and discussing the various periods thereof.

In the minds of some geologists, particularly at first sight, the diagram may appear to be either inappropriate or incomplete for a certain region which they may happen to have studied. In that case the more appropriate or more complete diagram should be drawn by them. Indeed they would begin with the recognition of the fact that all periods of time are probably not defined sharply, that events attributed to one period may be continuous or intermittent, that these events may extend over into the preceding or succeeding periods, that some periods will need repeating once or more often along the axis of time, and that events not taken into consideration here may require a period of time inserted between two which now appear in succession.

This diagram is intended only to show important and essential events with respect to migration and accumulation. It is not to be denied that lesser events may have their influence upon the pool which is, or is to be. As a concrete example, some regions may require a period of time between F and G for a repetition of marginal elevation accompanied by an accentuation of the geosynclinal folding and the primary folding of new local anticlines. It is, however, safe to predict in such cases that the new anticlines will be less productive than the old ones, if the accumulations are still of the first category, and that they are absolutely barren, if the accumulations have acquired the characteristics of the second category.

The classification of accumulated pools as to category may possibly be made on the basis of the age of the strata in which they lie. Accordingly, those in post-Mesozoic strata may be considered to be of the first category, while those in pre-Mesozoic strata may be taken to be of the second. However, in view of the uncertainty respecting those in Mesozoic strata, we should do well in using the mechanical criteria as a check upon such simple geological facts, lest we at some time find exceptional cases in either Cenozoic or Paleozoic strata.

The criteria for determining the time of accumulation under all circumstances are identical up to the end of the period F; thereafter they diverge for the special circumstances herein considered. All criteria as to accumulation include the criteria for determining the

time of unconformities. These pertain strictly to the events of the periods B, D, F, and G, which alternately cause major and minor discordances in the lay of younger strata. And with these minor discordances we must include the thickening or thinning of strata in their lateral extension. The intervening periods of C and E remain for migration and accumulation, and of these two the former is to be given preference, with the assignment of adjustments in the pools to the latter period.

It is clear, then, that when we have placed the features relative to major unconformities, minor unconformities, and changes in the thickness of strata in their proper position on the scale of geological time, the time of accumulation and the time of mechanical adjustments in the accumulation are definitely indicated in terms of the same scale of geological time.

The divergence beginning with G is such that there is possibly need for an uncharted period between G and H for further adjustments of those pools which retain the characteristics of the first category. There is certainly no need for such a period to accommodate pools which assume the characteristics of the second category. The impossibility of adjustments after the period F accounts for the numerous occurrences wherein pools are located peculiarly with respect to structures which have been affected by tertiary folding subsequent to the period F.

Criteria as to accumulation must include those only to be determined by observations in the oil and gas fields during drilling and production. These criteria not only indicate clearly the intensity of critical geological events in past geological time, but they also correlate events in the life of the accumulation with those very geological events. The behavior of any well in a field reveals the characteristics of the accumulation as to category. It is in the behavior only of edge wells in accumulations of the first category that the arrested mechanical adjustments of the pool, as suggested in the discussion pertaining to the period E, are readily detected.

Peculiar structural locations for accumulations so frequently noted in the region extending from north Texas to the province of Ontario have puzzled geologists. Anticlines with barren crests have condemned flanking lands only to have them proved productive years later. Terraces were ignored until found productive by chance. Shallow synclinal areas were condemned without drilling, and they frequently have been found very prolific afterwards. Obviously some one on each occasion suffered financial losses. But at a later time others gained.

In the geological profession these odd occurrences had evil effect. Not only were individual geologists awarded demerits for improper judgment, but the profession itself was often looked upon with disdain because of repeated failures. And more than that—they were, from 1865 to 1885, a challenge to the anticlinal theory of accumulation. We know of the opposition of J. P. Lesley, director of the Second Geological Survey of Pennsylvania, to this theory. His observations and studies covered the accumulations of his state and the adjoining ones. There, at that time, and to this day, those accumulations have the Paleozoic characteristics herein described as being of the second category. Fortunately Lesley did not win out, but he effectually cast a shadow upon the theory at the time. He certainly had a foundation for his opposition. He had to lose in the end, simply because the odd occurrences are far less frequent than the normal occurrences in accordance with structure, and the preponderance of these appeared by virtue of the inclusion of accumulations with Cenozoic characteristics described as being of the first category. In other words, if all accumulations were of the class found in Pennsylvania, West Virginia, Ohio, and New York, the anticlinal theory might today still be seriously questioned. But, be that as it may, we must admit that Lesley did not lose because of hypotheses suggested in the attempt to explain the peculiar locations on flanks, on terraces, and in synclines. Geologists have consistently refused to accept purely speculative notions. They rightfully prefer to have no explanation of phenomena rather than accept any which include contradictions of previously accepted logical principles concerning natural phenomena in general.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 852-914, 23 FIGS., 2 PLATES

STRATIGRAPHY OF THE BENDIAN OF THE OKLAHOMA SALIENT OF THE OUACHITA MOUNTAINS[1]

BRUCE H. HARLTON[2]
Tulsa, Oklahoma

ABSTRACT

The designation of the Bendian as a distinct period, which was proposed in 1934,[3] was based on a line of reasoning that covered all the facts known at that time. The tremendous increase in detailed knowledge since that time now occasions the placing of the formational boundaries on a firmer basis.

The new classification differs only in some important particulars from the 1934 classification. The Bendian is now known in greater detail than heretofore. It is divided into two series—the Pushmataha beneath and the Morrow above. The important features are the subdivision of the sedimentary sequence previously known as Stanley, Jackfork, and Johns Valley. The Pushmataha is divided into seven new formational units, and the Morrow into five.

INTRODUCTION

The process of geological research proceeds by way of the study of valuable exposures throughout a large area within a tectonic and stratigraphic province. Such research has been carried out in the Ouachita Mountains of Oklahoma and Arkansas, which comprise a belt about 220 miles long and 50–60 miles wide. An 18-month period of stratigraphic research in the field has yielded information of sufficient quantity and quality to establish correlations and taxonomy. As a result of these studies a reclassification of geologic nomenclature seems necessary.

Due to ever-broadening research, many changes of view have taken place with regard to the origin of the Ouachita Mountains. During the past few years much accurate information of great value has been gathered and remarkable progress has been made in stratigraphic geology. Interpretation of the complicated geologic history would be inadequate without this information. The completion of the contexture of minute details of stratigraphy, their geographic distribution and variation, is most essential. An endeavor has been made to work out the sequence, age, and history of the Carboniferous beds of the Ouachitas which are known as Bendian.

[1] Published by permission of Amerada Petroleum Corporation. Presented before the Association at Los Angeles, March 19, 1937. Manuscript received, April 16, 1938.

[2] Research geologist, Amerada Petroleum Corporation. For discussion of various problems the writer wishes to thank Hugh D. Miser, A. Rodger Denison, John L. Ferguson, and Thomas A. Hendricks. The illustrations were drawn by W. A. Carruth and W. A. McMorris. The block diagrams were drawn by C. E. Brehm.

[3] Bruce H. Harlton, "Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934).

The obscure relationship and special difficulties of the upper Bendian sediments have produced many troublesome and time-consuming problems. Many problems had to be solved so that the reference of the deposits to their original source would yield, before the orogenesis, a stratigraphically credible picture. With such conceptions in mind, most of these problems have now been solved, at least in principle and to a considerable extent in detail. It is, of course, realized that with advance in knowledge and further study previously unrecognized members of formational units may be segregated.

In order to understand fully the sedimentary sequence in the Ouachita Mountains, it is necessary to study the normal succession in the southern part of the area where broad gentle synclinal basins are prevalent. This study affords a means of recognizing the various units in the extremely complex frontal portion where the profuse number of strike faults obliterate many key beds. It is also shown that many of the new units which are introduced bear a striking similarity to those of the Ardmore basin and of the Arbuckle Mountains. A full knowledge of the problems of the Ouachitas then requires an acquaintance with the Bendian sequence of those areas.

In the selection of the type localities the greatest care was exercised in obtaining sections showing the best sedimentary sequence. In most places, it is practically impossible to refer to one particular locality and expect to find every unit belonging to a formation.

In the following pages the endeavor is to point out definitely known facts concerning stratigraphy. Some of the unsolved problems are discussed.

PROPOSED CHANGES

It is now proposed to subdivide the Bendian into two series—the older, the Pushmataha, and the younger, the Morrow. The name Pushmataha is here proposed for a series to consist of the Stanley group and most of the Jackfork. The upper 400–500 feet of sediments which were formerly called Jackfork, together with what is known as Johns Valley, Wapanucka, and what is now known as Barnett Hill, are here included in the Morrow series.

Further classification of the beds indicates that these series can be subdivided into at least twelve valid units of the rank of formations. Seven subdivisions are made in the Pushmataha in ascending order as follows: Tenmile Creek, Moyers, Chickasaw Creek, Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley. The first three of these comprise what was formerly called the Stanley, and the latter group are subdivisions of the former Jackfork. The

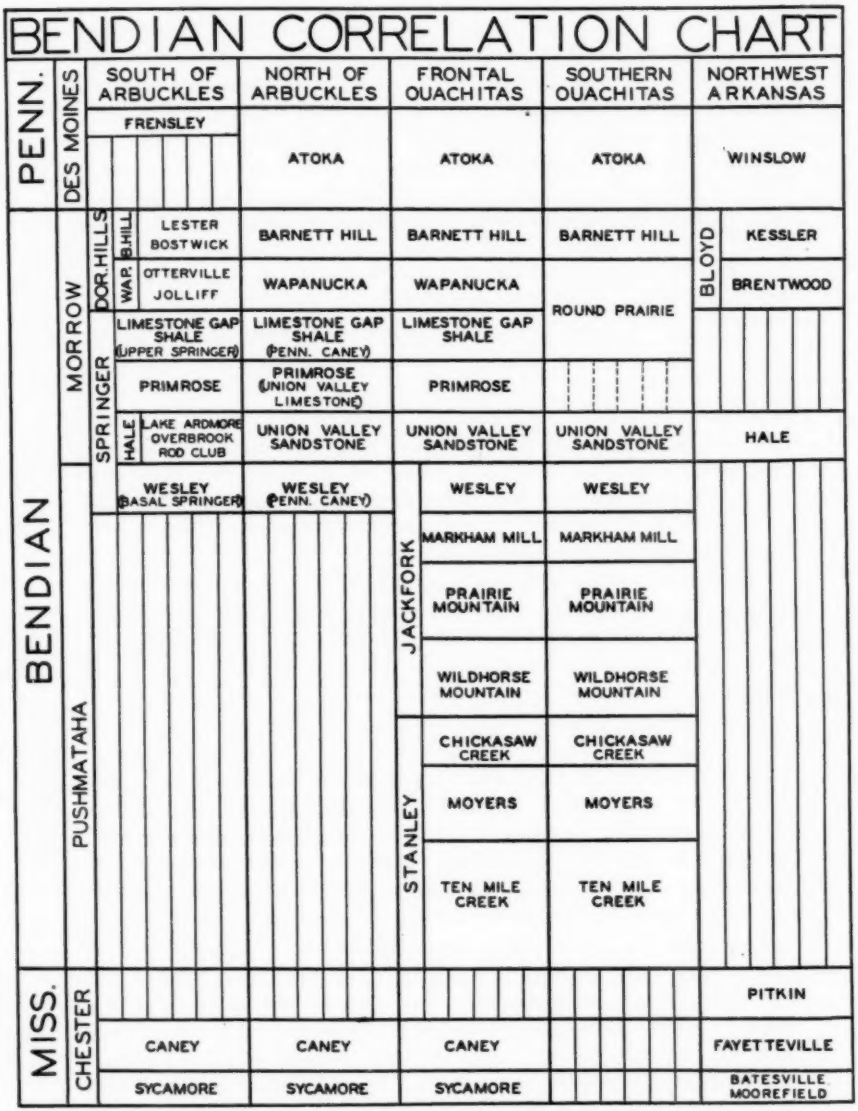


FIG. 1.—Correlation chart.

sequence of the Morrow series in the frontal Ouachitas now is divisible into five units, from the base upward, namely, the Union Valley, Primrose, Limestone Gap, Wapanucka, and Barnett Hill formations. The Union Valley is composed of the upper 400–500 feet of beds formerly placed in the upper Jackfork. In the southern Ouachitas the Primrose, Limestone Gap, and Wapanucka formations are so changed in lithologic character that they are not identifiable as separate units and are grouped together in the new formation here named and described as Round Prairie. The classification of the Primrose to the Wapanucka, inclusive, in the standard section is pertinent to the placement of the Round Prairie formation, for whether they are synchronous in part or not the latter has a fauna that is most similar to them. Therefore, their faunal characteristics are sufficient to make them useful in interpretation of correlative beds.

The general relation of the Bendian section in the Ouachita Mountains is shown in the correlation chart (Fig. 1). In the arrangement of the new formational divisions the endeavor is to apply all adopted principles and criteria in consistent accord with the knowledge of the facts. All divisions are based on diastrophic criteria of unconformity, change in character of deposits, and the general aspect of the fauna. Of particular significance is the fact that each of them is governed by a distinct geologic history. Taff selected names in areas where detail field work now shows that the beds were in a complicated relationship and normal stratigraphic sequence is not revealed. Detail studies show that in and adjacent to Prairie Mountain, T. 1 S., R. 12 E., the full Bendian section is exposed in undisturbed sequences, which gives excellent opportunity for making definite subdivisions of the group divisions. Many of the new formation names are taken from this area, and the old names are retained as group subdivisions. Prairie Mountain may well be considered the type for the complete Bendian section in the Ouachita Mountains. The changes proposed on the chart (Fig. 1) are here discussed.

Pushmataha Series

In the Pushmataha series the clastic facies are dominant and at numerous intervals siliceous shales have been laid down with conodonts, spores, and radiolaria. In nearly all of these siliceous shales a peculiar type of conglomerate is encountered, which is discussed in the following pages under each formation. The Pushmataha series can be subdivided into two groups, namely, Stanley below and Jackfork above. The boundary of the Stanley group has been moved up in the section approximately 600 feet and now includes the massive sand-

stones formerly mapped as basal Jackfork. The Jackfork group is divided between the Pushmataha and the Morrow groups.

STANLEY GROUP

The Stanley group, which was named by Taff and apparently received its name from the village of Stanley in the center of Sec. 24, T. 1. N., R. 17 E., is exposed only in part at that locality. In all parts of the Ouachita Mountains, this group is divisible into three good formational units which can and should be mapped separately and therefore demand definition.

Of the three divisions, the most easily recognized is the lower, which makes up the valleys of the entire mountain area. This division, for which the name Tenmile Creek formation is proposed, consists of alternating sandstones and shales, aggregating a thickness of about 5,650 feet. Near the middle a fossiliferous siliceous shale is found. The basal part is overlapped to the south by the Trinity sandstone, and nowhere is the base exposed in such a way that a complete thickness can be measured. The overlying formation, for which the name Moyers is proposed, makes up the lower slopes of the hills, where adjacent to the valley-making Tenmile Creek. It is readily distinguishable by fossiliferous siliceous shale at the base, and is composed of alternating sandstones and shales aggregating a measurable thickness of about 1,100 feet. The third, or upper, division, for which the name Chickasaw Creek siliceous shale is here proposed, marks the dividing line of the Stanley and Jackfork and is one of the most widespread and best displayed siliceous shales in the entire Ouachita Mountains.

JACKFORK GROUP

The Jackfork group, also named by Taff, received its name from Jackfork Mountain, Oklahoma. The sequence in this faulted mountain is now known to be made up in part of the Moyers formation of Stanley age, and other beds are in a complex relationship. The best exposure of these beds in undisturbed sequence is now believed to be in Prairie Mountain, T. 1 S., R. 12 E.

For the lower unit of the Jackfork group the name Wildhorse Mountain is here proposed. This unit consists of a massive sandstone near the base, which is generally succeeded by thin-bedded sandstones and intercalated shales. At the top of this formation is a very massive solid sandstone about 60 feet thick, which is the most prominent ridge maker in the Ouachita Mountains. The thickness of the Wildhorse Mountain formation varies conspicuously from west to east.

In the Tuskahoma syncline, T. 2 S., R. 16 E., its type locality, it approximates 3,600 feet, though in the Round Prairie syncline in Ts. 1 and 2 S., R. 12 E., it measures scarcely 1,000 feet.

Above this uppermost massive sandstone one encounters another siliceous shale, followed by alternating sandstones and shales, for which beds the name Prairie Mountain formation is proposed. The thickness of this formation is likewise variable: in the Round Prairie syncline it approximates 1,350 feet, but in the Tuskahoma syncline it is about 4,300 feet. Approximately 450 feet above the base of this formation is a zone of alternating green and maroon shale several hundred feet in thickness, of widespread distribution. For this zone the name Prairie Hollow is proposed.

The Prairie Mountain is succeeded by another siliceous shale which is followed in turn by shales and thin sandstones aggregating a thickness of about 340 feet. For this division the name Markham Mill formation is here proposed.

The Markham Mill is succeeded by a massive siliceous shale 100–500 feet in thickness which not only has the widest distribution, but also is one of the most diagnostic and easily recognizable of all the siliceous shales. For this the name Wesley is here proposed.

Morrow Series

The proper delineation of the Morrow series in the Ouachita Mountains is one of the most difficult problems in the study of the Bendian history. Detailed studies of the sediments demonstrate that the exact equivalent of the Morrow in northwest Arkansas is found in the frontal belt of the Ouachitas. However, in this area the beds are so complexly interrupted by strike faulting, thrusting, and overturning that the stratigraphic sequence and true thickness of the different formations are difficult to determine. In the Prairie Mountain area, however, the Morrow occurs in undisturbed sequence above the Pushmataha series and the formational subdivisions are distinct.

In this area the Morrow is subdivided into Union Valley, Round Prairie, and Barnett Hill. The basal or Union Valley unit, which is the upper part of the former Jackfork formation, is recognized as the extension of the Union Valley sandstone of the Arbuckles. It is approximately 400–500 feet thick and consists of sandstones and shales. The overlying Round Prairie formation is largely dark gray shale with thin-bedded calcareous sandstones near the middle; it contains, however, two beds of bouldery shale, one at the base and another about 100 feet above, near the top of the formation. The boulders in these shales occur in sizes ranging from sand grains to masses 6 feet

in diameter. These masses are made up of material from the Simpson of Ordovician age to the Pushmataha of Bendian age. The uppermost formation of the Morrow series is made up of calcareous, fossiliferous sandstones and shales and contains a siliceous shale near the base. For this formation the name Barnett Hill is here proposed.

In the frontal belt of the Ouachitas the Union Valley formation and the Barnett Hill formation are so similar to the exposures at Prairie Mountain that the correlation is unquestioned. The intervening material, however, is definitely divisible into three formations which are lithologically dissimilar to the Round Prairie formation with which it correlated.

In August, 1934, the writer[4] proposed to subdivide the Wapanucka into basal, middle, and upper units. It was thought to apply these temporary formational divisions as far as a liberal interpretation of the facts permitted at that time. Since that time further study has shown that additional definite lithologic subdivisions can be made and other changes are desirable. It is now proposed to apply the names Primrose and Limestone Gap formations to the unit heretofore designated as basal Wapanucka. The name Wapanucka is reduced in rank and applied to the middle unit; to the upper unit, previously considered the upper member of the Wapanucka, the name Barnett Hill formation is now applied.

In the frontal belt, then, the Morrow series comprises five formational units from the base upward, namely, Union Valley, Primrose, Limestone Gap, Wapanucka, and Barnett Hill. The Union Valley formation is described in a preceding paragraph. To the next succeeding formation the Ardmore basin term Primrose is applied. It consists largely of siliceous limestones and shales. In the Ouachita Mountains its maximum thickness is unknown. It has not been measured in excess of 20 feet, but may greatly exceed this thickness. The Primrose, like the overlying Wapanucka and Barnett Hill, was erroneously called Chickachoc by Taff. In the Arbuckle Mountains it is only a few feet thick; in the Ardmore basin, where it reached its greatest development, it measures in many places more than 600 feet. For the shale body overlying the Primrose, the name Limestone Gap is here proposed. Its thickness in the Ouachita Mountains is questionable because it is found chiefly in the strike-faulted frontal belts. Exposures of 50–100 feet have been measured. The name Wapanucka is retained for the main lower massive limestone as Taff undoubtedly intended the usage. Its thickness varies—its maximum is about 250 feet. The Barnett Hill is a clearly defined lithologic and

[4] Bruce H. Harlton, *op. cit.*, pp. 1023–25.

paleontologic unit above the Wapanucka. This unit was locally assigned by Taff to the Atoka formation, but in other areas it was included in the Wapanucka. In the writer's 1934 classification it was assigned under the provisional designation "upper Wapanucka" and much evidence has been found favoring the conclusions then presented. This formation changes laterally within short distances, and is a typically overlapping deposit. Its thickness consequently varies greatly and at the two selected type localities it measures 415 and 760 feet, respectively.

Pushmataha and Morrow History

Before passing through the details of the stratigraphy, it is considered important to present a short generalized conception of the order of geologic events during the deposition of the Pushmataha and Morrow series of the Bendian. Thus a foundation may be laid for an understanding of the several very exceptional features discussed.

PUSHMATAHA HISTORY

The most impressive characteristic of the Pushmataha series is the great volume of clastic deposits. Since the subsidence was enormous and rapid, the uneven shallow basin sank coincidently with the in-filling of sediments. The shallow-water character was maintained even when the basin had sunk to a depth of thousands of feet, as manifest by the abundance of ripple and rill marks. Due to crustal tension, which unsettled the isostatic equilibrium, there was intermittent submergence in different places. This is supported by the abundance of terrestrial flora at numerous different horizons. *Lepidodendron*, *Calamites*, and *Sigillaria* are the most plentiful specimens.

The belt of mobility which supplied the clastic sediments during Pushmataha time was Llanoria. This continental chain experienced repeated upheavals probably due to the decrease in weight by the removal of the sediments. The loading of the sediments in the Pushmataha geosyncline in turn caused repeated sinking.

The Pushmataha geosyncline came into existence by a diastrophic disturbance of consequence as evidenced by the Hot Springs conglomerate, well exposed in and near the city of Hot Springs, Arkansas. This was followed by vulcanism represented by the Hatton tuff lentils named and discussed by Miser.[5]

As the geosyncline became deeper its thick prism of sediments

[5] H. D. Miser, "Mississippian Tuff in the Ouachita Mountain Region," abstract. *Bull. Geol. Soc. America*, Vol. 31 (1920), pp. 125–26.

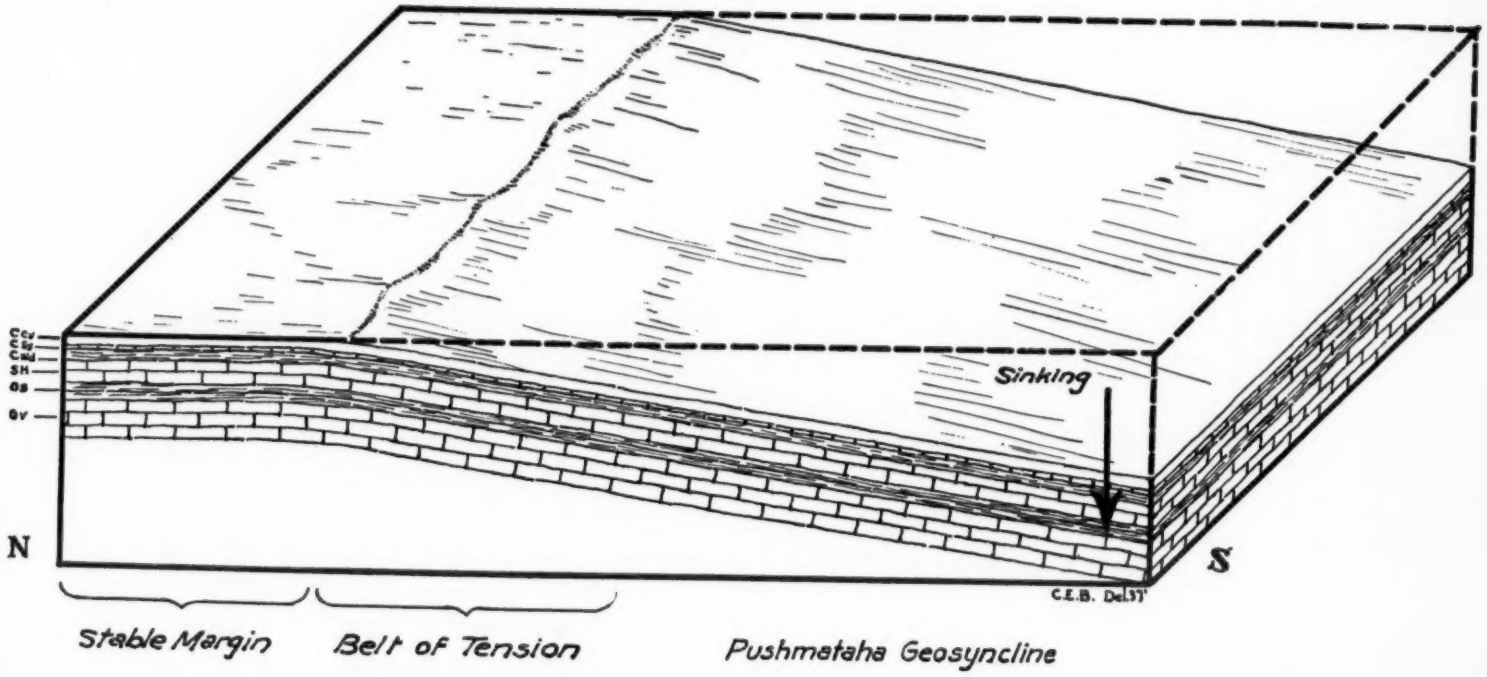


FIG. 2.—Block diagram showing geosynclinal development at end of Moyers time.

must have relieved its accumulative stresses outward and toward the margin of the basin. At last a point was reached when the descending crust, unable any longer to withstand the accumulative lateral tension, was forced to find relief along its entire periphery, thus initiating the incipient stages of a belt of fracturing (Fig. 2). With further subsidence many of the fractures developed into normal faults. The breaking along the margins is clearly evident in the frontal parts of the mountains. Probably sufficient relief was developed along the normal fault scarps to supply the erratic boulders found in the Markham Mill siliceous shale (Fig. 3).

Toward the close of Pushmataha (Jackfork) time, the Ouachita geosyncline had sunk to its greatest depth. More than 13,000 feet of clastic sediments had been laid down in the southern Ouachita area. Compressive stresses became operative at that time, inaugurating the building of the Ouachitas.

MORROW HISTORY

At the beginning of the subsequent Morrow stage, a new geosyncline began its development on the north and west and spread across the frontal part of the Ouachita area (Fig. 4). The mobility, which was very pronounced during the early stages of Morrow time, and locally during the later stages, deformed the southern margin of the basin so as to suit its need and created narrow deep inlets at different places.

The initial stage of the Morrow geosyncline was a scene of restless conflict between diastrophism and erosion. On its ever-changing sea floor, sandstones, shales, and conglomerates were laid down. The conglomerates herald one of the most important orogenic paroxysms in the Mid-Continent. The stratigraphic position of the massive conglomerate, composed largely of Ordovician fragments, located at Boles, Stapp, and other places, has now been determined as early Morrow in age. Due to the extreme coarseness and thickness of the conglomerate it can not be denied that the material was derived from a mobile highland which was lifted above the sea, at least locally, leaving it a prey to ever active forces of erosion. This highland undoubtedly was located near the frontal part of the mountains. Therefore, the opening stage of the Morrow deserves high rank in the classification of orogenic movements. It is with no small degree of trepidation that, according to the history outlined, the Ouachitas should be credited with having reached a great height at that time. The block diagram (Fig. 5) shows the closing stages of Morrow time. The final culmination of the Ouachitas undoubtedly occurred after

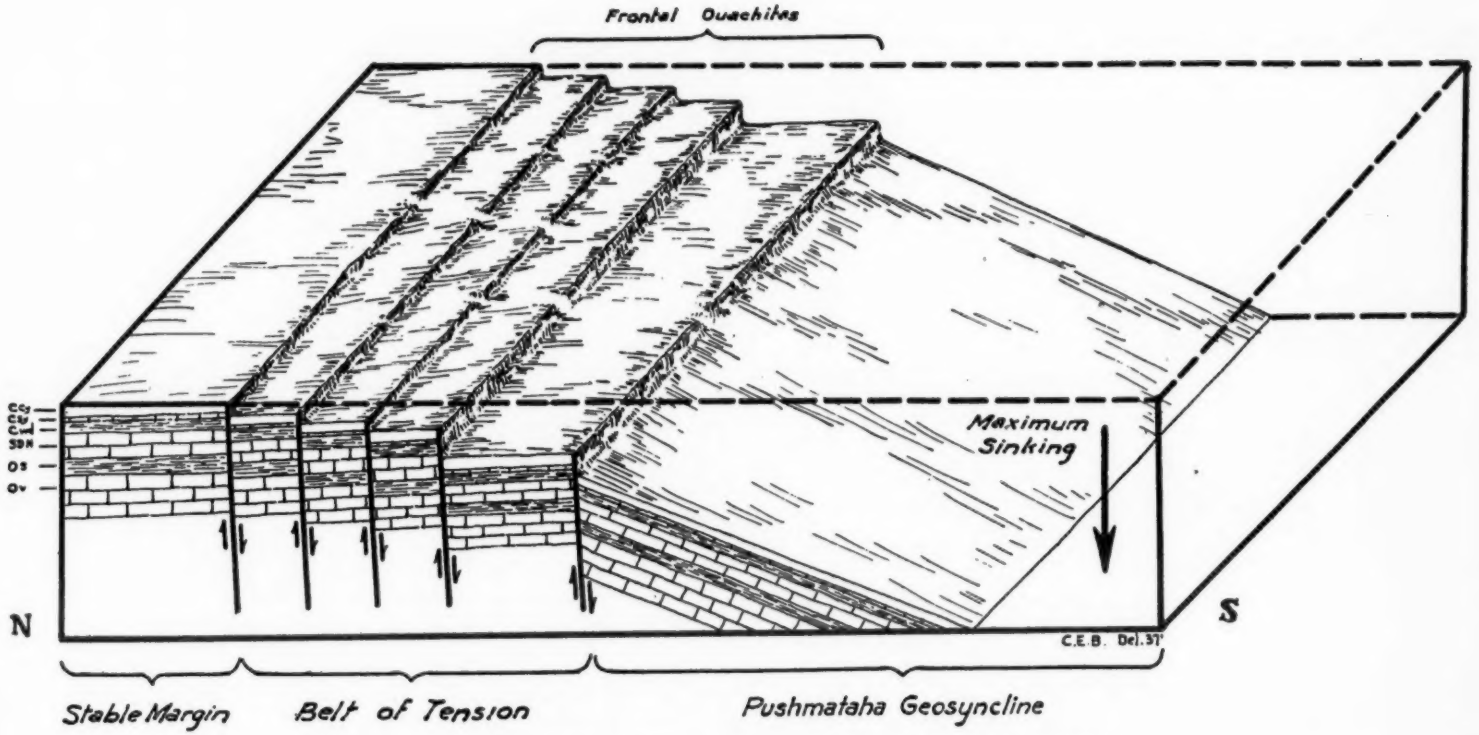


FIG. 3.—Block diagram showing geosynclinal development at end of Prairie Mountain time.

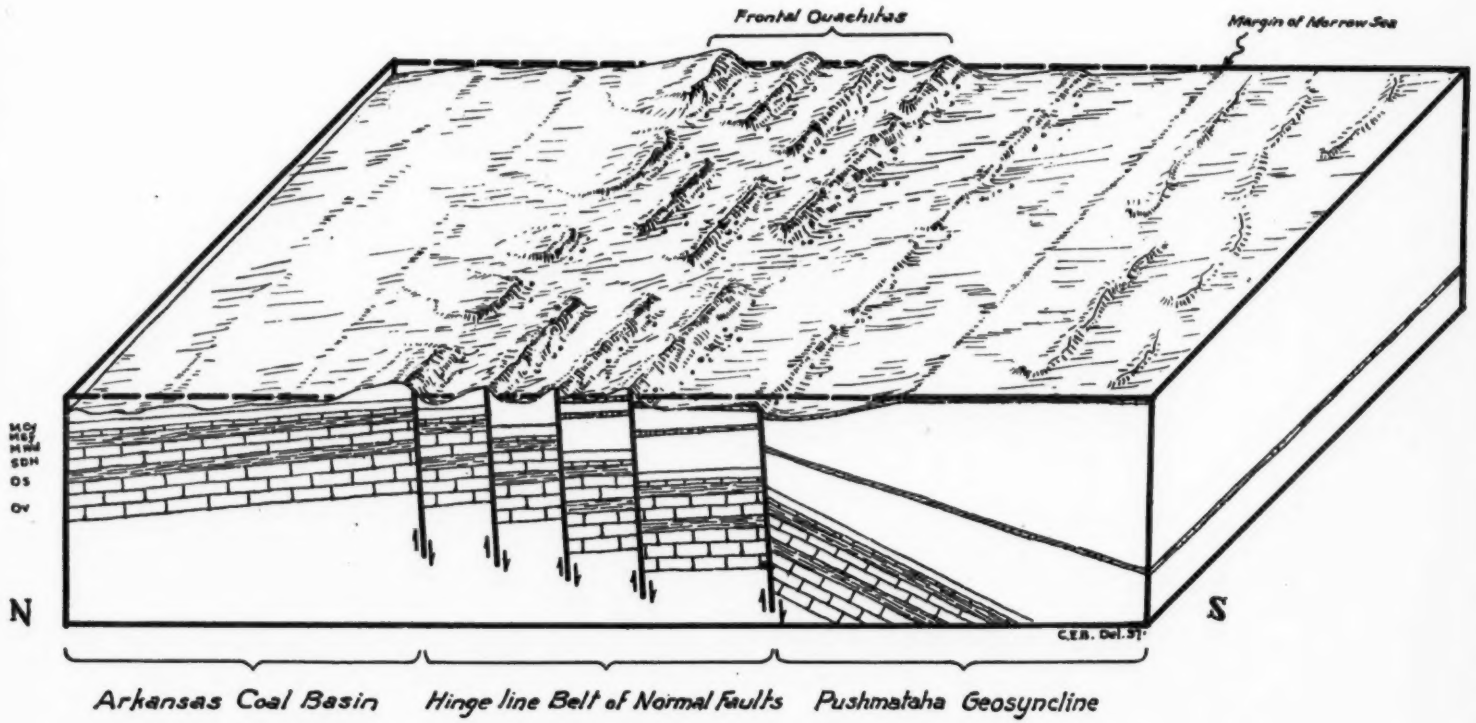


FIG. 4.—Block diagram showing development of new Morrow geosyncline.

the Morrow in late Boggy time, which records the last definite evidence of movement. Thus the Ouachitas of to-day are shown to be the result of numerous recurrent movements extending through considerable geologic time.

Description of Formations

Stanley Group

Tenmile Creek Formation

Distribution.—The Tenmile Creek formation is the great valley maker of the southern Ouachita Mountains. It is predominantly shale with minor thin sandstones and here and there massive sandstones. Despite the massive character of all of the sandstones, their high argillaceous content causes them to be easily weathered, so that they do not produce prominent ridges and are but little more resistant than the surrounding shale. Subsequent erosive forces have produced a profuse amount of débris which now covers the greater part of the broad valleys which are the main agricultural areas of the Ouachitas. Such valleys, as McGee Valley, Jumbo Valley, Stanley Valley, are underlain by the Tenmile Creek.

Thickness.—This formation is developed to extraordinary thickness in the southern border region of the area. According to present information the maximum thickness for the region to the Cretaceous overlap is about 5,650 feet. The thickness of the lower part to the Cretaceous overlap aggregates 2,150 feet; the upper part, which includes a siliceous shale at the base, aggregates 3,500 feet. The variation in thickness of the Tenmile Creek is difficult to determine, because most of the valleys are characterized by strike faults.

Lithologic character.—In order that the character and relations of this subdivision be clearly understood, a type section (Fig. 6) was selected 3 miles east of the settlement of Miller in T. 3 S., R. 15 E., and is indicated on the map by the letter *A*. For detail description see Figure 7.

The lithologic character of the lower part of this formation consists of finely laminated olive-green shales and platy, silty shales, alternating with massive and thin-bedded greenish colored, poorly sorted silty, fine to coarse, rounded to subangular sandstones. Practically all of the sandstones contain considerable clay between the sand grains. Microscopic examination of many sandstones show them to consist of alternating minute laminae of clay with ripple marks at the bottom, followed by fine siltstone and then by sandstone.

Most of the sandstones of the lower part of the Tenmile Creek

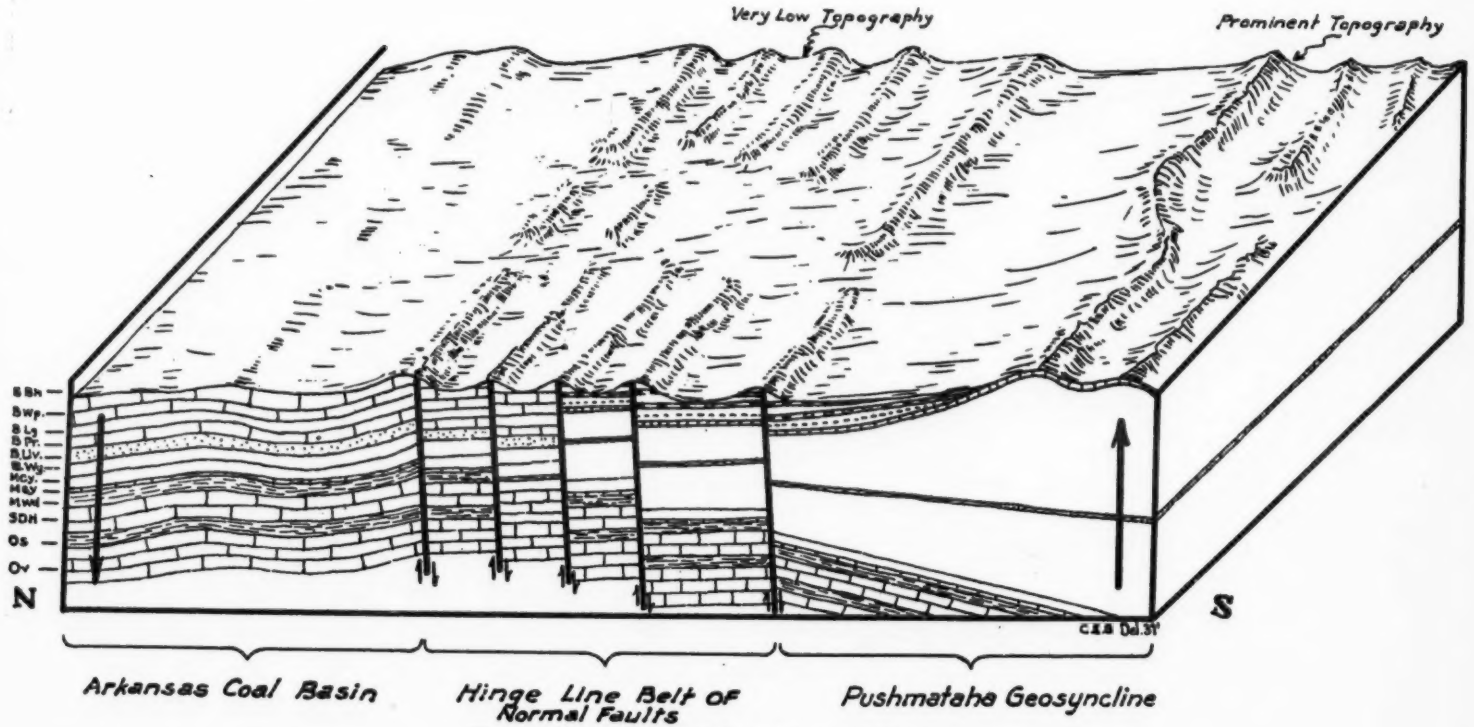


FIG. 5.—Block diagram showing closing stage of Morrow time.

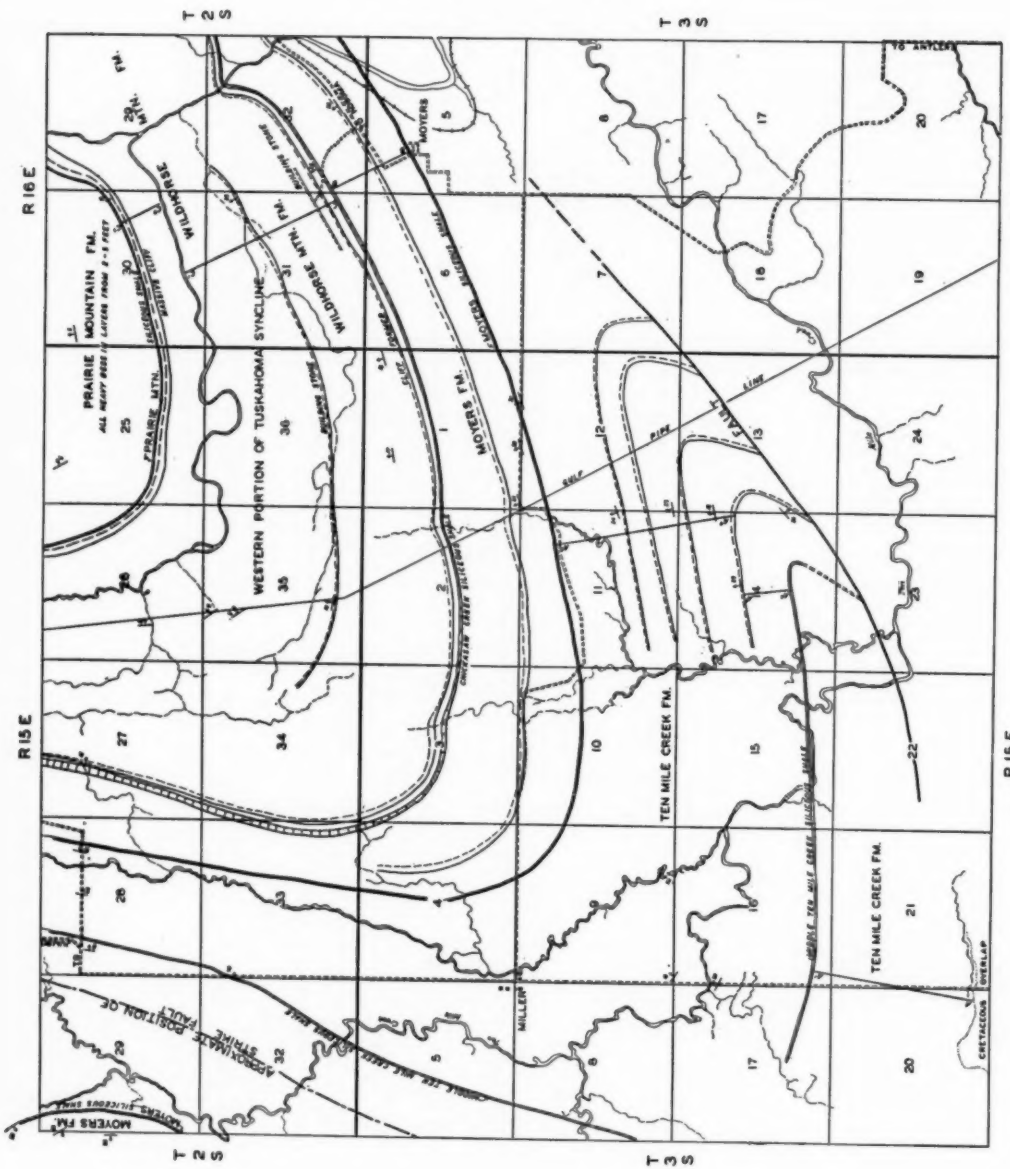
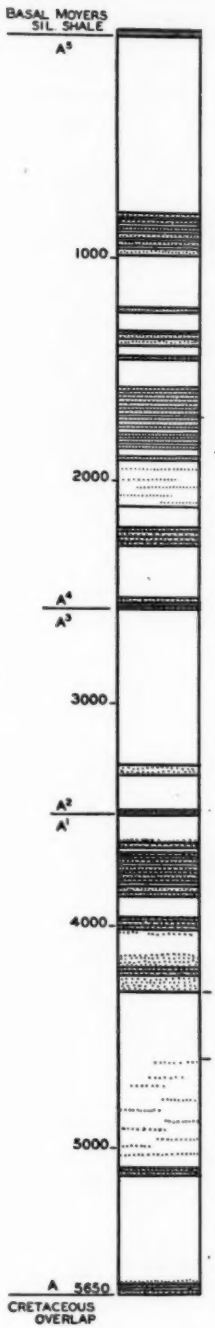


FIG. 6.—Map of western part of Tuskahoma syncline.

FIG. 6.—Map of western part of Tuskahoma syncline.

TEN MILE CREEK FORMATION

SEE MAP FIG. 6 LINE A



COVERED

MASSIVE AND THIN BEDDED, TAN, HIGHLY ARGILLACEOUS, ROUNDED TO SUB-ANGULAR, FINE TO MEDIUM SANDSTONE WITH MANY INCLUDED WHITE SPECKS AND BODIES, PROBABLY RADIOLARIA.

COVERED, EXCEPT TOP 50 FEET WHICH CONSISTS OF GREENISH, ARENACEOUS SHALE.

THIN BEDDED, DARK GREEN, HARD, ARGILLACEOUS SILTSTONE.

TOP 4 FEET THIN BEDDED, DARK GREEN, HARD, ARGILLACEOUS SILTSTONE GRADING DOWN TO MASSIVE, ARGILLACEOUS SILTSTONE WITH MICA.

OLIVE GREEN SHALE.

THIN BEDDED, GREEN, HIGHLY ARGILLACEOUS SILTSTONE TO FINE SANDSTONE.

MASSIVE AND THIN BEDDED, VERY FINE TO MEDIUM, ARGILLACEOUS SANDSTONE WITH PROFUSION OF WHITE SPECKS - MATRIX IN THE MAIN IS A SILTSTONE. MANY STREAKS CONTAIN GREAT AMOUNT OF LARGE, ROUNDED, FROSTED GRAINS.

OLIVE GREEN SHALE WITH MANY CONCRETIONS.

INTERCALATED ARGILLACEOUS SILTSTONE WITH MANY WHITE SPECKS.

COVERED

MASSIVE AND THIN BEDDED, VERY FINE TO MEDIUM, ARGILLACEOUS SANDSTONE AND INTERCALATED TAN GREENISH SHALE.

COVERED

THIN AND MASSIVE BEDDED, GREEN, FINE TO COARSE, ROUNDED TO SUB-ANGULAR SANDSTONE, MATRIX MOSTLY SILTSTONE. MANY INCLUDED WHITE YELLOWISH SPECKS - SOME MICA.

VERY THIN BEDDED, ARGILLACEOUS SILTSTONE AND SILTY SHALES.

BLUE SILICEOUS SHALE.

OLIVE GREEN, SOFT, FLAKY, PAPERY SHALE.

MASSIVE AND THIN BEDDED, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE WITH MANY WHITE SPECKS.

THIN BEDDED, ARGILLACEOUS SILTSTONE TO FINE SAND - SOME MICA.

GREEN, MASSIVE AND THIN BEDDED, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE GRADING TO THIN BEDDED ARGILLACEOUS SILTSTONE.

COVERED, BUT SOIL SUGGESTS SAME AS BELOW.

LIGHT GREEN TO OLIVE GREEN, SILTY SHALE ALTERNATING WITH GREENISH, ARENACEOUS SHALE.

GREEN AND MAROON MOTTLED, ARGILLACEOUS SILTSTONE TO FINE SANDSTONE - SOME INCLUDED MEDIUM-COARSE, ROUNDED GRAINS - SOME MICA. BECOMES MASSIVE.

MAROON, CONCHOIDAL SHALE & INTERCALATED THIN STREAKS OF DARK GREEN, ARGILLACEOUS SILTSTONE TO FINE SANDSTONE - MUCH MICA.

MAROON, VERY FINE TO MEDIUM COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE. MANY SEAMS OF CALCITE.

MASSIVE, VERY FINE TO MEDIUM, HIGHLY ARGILLACEOUS, SOFT SANDSTONE. MATRIX MOSTLY SILTSTONE.

FIG. 7.—Detailed description of Tenmile Creek formation.

contain a great amount of argillite, which in places is closely intermixed, or in blebs, pockets, or streaks. In addition, the lower exposed 700–800 feet of sediments vary in color, alternating from green to maroon in both sandstones and shales. The color variation, which was observed in most places immediately north of the present boundary of the overlapping Trinity sandstone, appears to be a phenomenon due to the Cretaceous overlap.

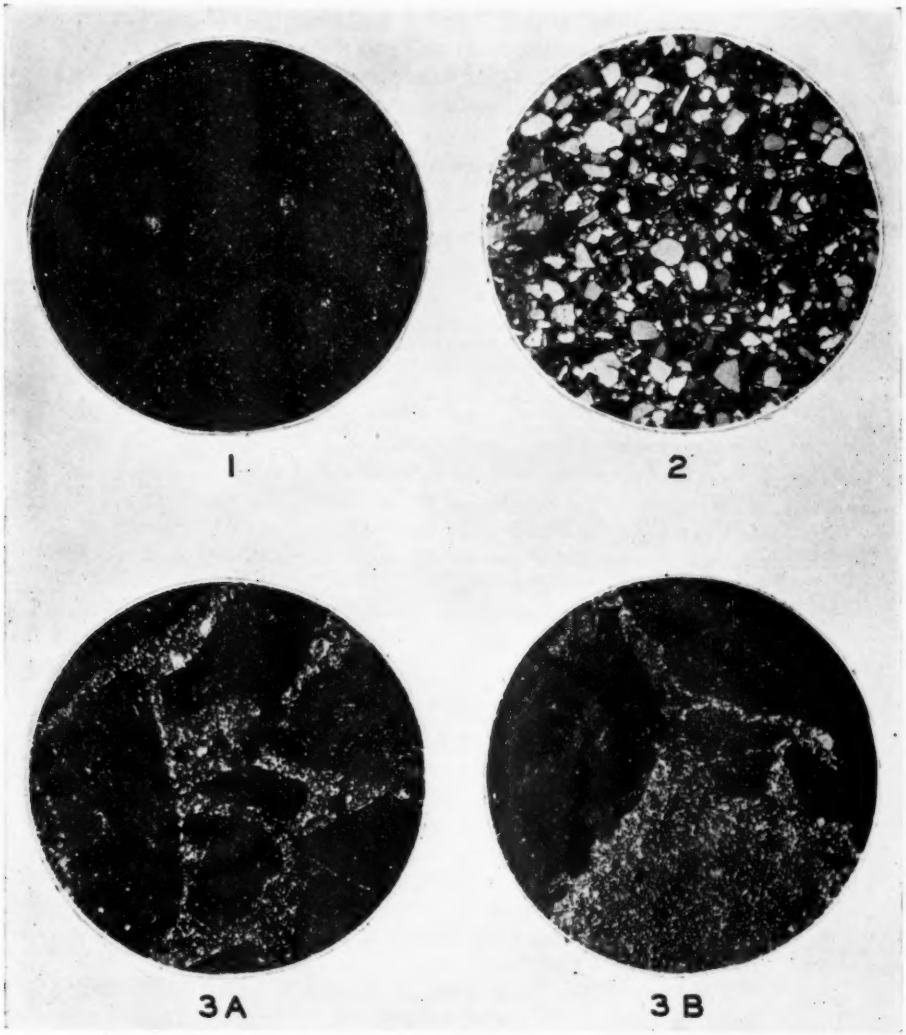
The siliceous shale, which occurs at the base of the upper part, has been traced and mapped accurately in the Jumbo area in Ts. 2 and 3 S., R. 15 E. The mapping of this shale elsewhere in the mountains requires a great amount of additional detail work and, since it is poorly represented in known sections, a lower divisional name is found undesirable at present. The alternating sandstones and shales above the siliceous shale are like those of the lower part, except that many of the sandstones show a considerable decrease in argillite. The silty shales contain many small elongate and beautifully rounded to subrounded concretions, which are convex upward and flat or concave at the base. These concretions are composed of argillaceous siltstone. Also, many concretion-like argillaceous silty masses which range in thickness from 1 to 3 feet are found in many places. Numerous olive-green papery shales contain irregular argillite concretions. The shales in the upper part of the Tenmile Creek are predominantly blue-gray to dark gray in most parts of the area. This shale has extremely abundant development of cone-in-cone structure.

The sandstones of the entire Tenmile Creek formation have a matrix of siltstone. The bedding planes are obscure in all of the sandstones. Muscovite in very fine flakes is a common constituent. Carbonized plant fragments are found in most of the sandstones.

The upper 800 feet of the section are covered at the type locality. However, in many places in the mountains there is exposed, approximately 300 feet below the top of the formation, a maroon shale zone, 40–50 feet in thickness. An excellent locality is on the northwest side of Prairie Mountain, Secs. 27 and 34, T. 1 S., R. 12 E. (Fig. 9). This maroon shale zone is very diagnostic and easily identifies the sequence in which it occurs as the Tenmile Creek.

The basal part of the Tenmile Creek is well exposed on the east side of Black Knob Ridge, in T. 1 S., R. 12 E. Near the base gray fossiliferous siliceous shale about 20 feet thick is encountered. Numerous thin sections were made of this basal as well as the middle, siliceous shale and all of them show a groundmass with the following description.

Clay with a profuse number of shreds of weathered volcanic glass. The refraction index of the shreds is very low. The much included organic material is mostly black (Pl. I, Fig. 1)



EXPLANATION OF PLATE I

1.—Photomicrograph of middle siliceous shale of Tenmile Creek formation. Three-fifths mile N. of SE. cor., Sec. 4, T. 3 S. R. 15 E. Showing groundmass of clay with much disseminated volcanic glass. (×14).

2.—Photomicrograph of basal Tenmile Creek sandstone, from east side of Black Knob Ridge, center, NW. ¼, NE. ¼, SE. ¼ Sec. 29, T. 1 S., R. 12 E. Poorly sorted fine to medium-grained angular to rounded quartz grains with fragments of feldspar, mica and numerous heavy minerals. (×14).

3A.—Photomicrograph of chert conglomerate in Chickasaw Creek siliceous shale from type locality, center, S. line of SW. ¼, 600 feet N. of Sec. line, Sec. 7, T. 1 S., R. 13 E. Chert pebbles surrounded by matrix of chert. (×14).

3B.—Photomicrograph of another part of thin section shown in 3A. The left side of section shows dark siliceous shale pebbles with much organic material; upper right shows silica-filled fractures. (×14).

About 600 feet north of North Boggy Creek, in Sec. 29, T. 1 S., R. 12 E., on the east side of Black Knob Ridge, the Arkansas novaculite is overlain by alternating sandstones and shales. Thin sections were made of most of the basal sandstones and some have the following composition.

Coarse, well worn, rounded quartz grains, cemented with cryptocrystalline silica and containing red-brown to brown organic material. The sandstone was originally highly calcareous

Another interesting sandstone observed is gray, weathered tan, fine to coarse, angular sandstone. The thin section shows the following.

Poorly sorted, fine, medium, coarse, angular to rounded quartz grains with some orthoclase feldspar, and shreds of mica, and a considerable amount of heavy minerals, with zircon in the main, garnet, *et cetera*. This is detrital sandstone, possibly derived from a mechanically eroded surface (Pl. I, Fig. 2)

General weathering character.—The sandstones of this formation weather to small masses, irregular in outline. The color on fresh surfaces is light green and weathers to brownish green. The basal as well as the middle siliceous shales of the Tenmile Creek weather to light bluish gray. In the Potato Hills the basal siliceous shale is mostly replaced by chalcedony. Furthermore, there occurs at the base a coarse conglomerate, now highly silicified.

Fauna.—The basal as well as the middle siliceous shales contain a profusion of spores and conodonts. The latter, in the basal siliceous shales, are very diagnostic.

MOYERS FORMATION

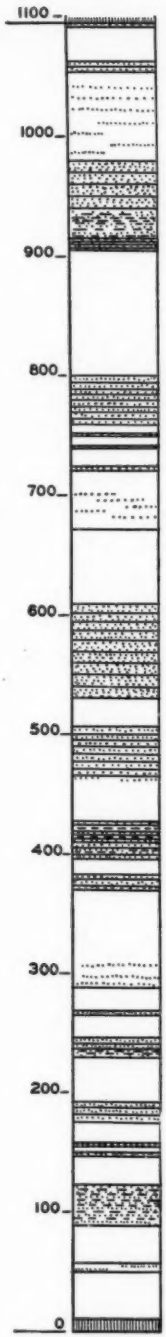
Distribution.—The Moyers formation makes up the lower slopes of the mountains and ordinarily rises from 100 to 150 feet above the valley floor. It is an easily mappable unit in the Ouachita Mountains, for the massive sandstones make prominent ridges, and the benches at low dip are very prominent. The flanks of the Tuskahoma syncline located in Ts. 1 and 2 S., R. 16 E., and extending northeastward between the villages of Clayton and Sardis, offer a splendid example of this. The siliceous shale which occurs at the base is of wide distribution.

Thickness.—The thickness of the Moyers formation at the type locality is approximately 1,100 feet, of which the basal siliceous shale ordinarily measures about 20 feet. In the western part of the Ouachitas, in T. 1 S., R. 12 E., a thinning of about 200 feet is observed.

Lithologic character.—An excellent type section (Fig. 6) for the formation was selected at, and north of, the village of Moyers, in T. 2 S., R. 16 E., and is indicated on the map by the letter *B*. For detail description see Figure 8.

MOYERS FORMATION

SEE MAP [FIG. 6] LINE B



THIN BEDDED, GREENISH, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE.
OLIVE GREEN, FLAKY TO SPLINTERY SHALE.
MASSIVE, GREENISH, ARGILLACEOUS, MICACEOUS SILTONE, SOME INCLUDED FINE TO MEDIUM GRAINS.

OLIVE GREEN, CONCHOIDAL SHALE WITH OCCASIONAL THIN STREAKS OF SANDSTONE.

VERY MASSIVE, SILTY, TO FINE TO MEDIUM SANDSTONE, WITH MANY INCLUDED VERY LARGE, ROUNDED, FROSTED GRAINS. MANY WHITE SPECKS.

TAN GREENISH, SOFT, HIGHLY ARGILLACEOUS, FINE TO COARSE SANDSTONE.
THIN BEDDED, GREENISH, FINE TO COARSE SANDSTONE.

MASSIVE AND THIN BEDDED, TAN GREENISH, FINE TO COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE WITH IRREGULAR LAMINAE.

VERY THIN BEDDED SANDSTONE.

GREENISH TAN, VERY HARD, COARSE TO FINE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE. WEATHERS TO VERY LARGE, SQUARE, BLOCKY SLABS.
DARK GREEN, GRANULAR, HIGHLY CALCAREOUS SHALE WITH SEAMS AND NODULES OF FINE, ARGILLACEOUS SANDSTONE AND PROFUSE AMOUNT OF CONE IN CONE STRUCTURES.

OLIVE GREEN, FLAKY TO SPLINTERY SHALE.

VERY MASSIVE, TAN GREENISH, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR SANDSTONE WITH A MATRIX OF MOSTLY FINE SILTSTONE - MANY INCLUDED WHITE SPECKS. MAKES VERY PROMINENT BENCH.

OLIVE GREEN SHALE.

VERY MASSIVE, TAN, VERY FINE TO MEDIUM, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE - MATRIX PREDOMINANTLY SILTSTONE.
THIS SANDSTONE WAS INCLUDED BY TAFF AS THE BASAL MEMBER OF THE JACKFORK.
GREENISH GREY, SPLINTERY SHALE, UPPER 3 FEET CONTAINS THIN SEAMS OF GREENISH, FINE ARGILLACEOUS SANDSTONE.

MASSIVE, TAN GREENISH, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE, WEATHERS TO LARGE SHELLS. MAKES PROMINENT BENCH - SOMETIMES ONE NEAR TOP, ANOTHER ONE NEAR BASE.

MASSIVE AND THIN BEDDED, VERY FINE TO MEDIUM, SUB-ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE WITH A MATRIX OF MOSTLY FINE SILT.
MAKES PROMINENT BENCH.

THIN BEDDED, GREEN, ARGILLACEOUS, VERY FINE TO COARSE, QUARTZOSE SANDSTONE, GRAINS SPLIT THROUGH ON A FRACTURE.

GREENISH, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR, HIGHLY ARGILLACEOUS SANDSTONE. MANY WHITE SPECKS.
GREENISH, VERY FINE TO COARSE, ROUNDED TO SUB-ANGULAR, ARGILLACEOUS SANDSTONE WITH PROFUSION OF WHITE SPECKS.
TAN GREENISH, MOTTLED, HIGHLY ARGILLACEOUS, FINE TO COARSE, ROUNDED TO SUB-ROUNDED SANDSTONE.
BLUE GREENISH, SOFT, FLAKY SHALE.
MASSIVE, TAN TO WHITISH GREY, VERY FINE TO MEDIUM, SUBANGULAR, ARGILLACEOUS SANDSTONE. SOME INCLUDED LARGE GRAINS. MATRIX MOSTLY FINE SILT.

MASSIVE, FINE TO COARSE, ROUNDED TO SUBANGULAR SANDSTONE.
BLUISH, SOFT, FLAKY SHALE.
TAN GREENISH, MOTTLED, HIGHLY ARGILLACEOUS, FINE TO COARSE, ROUNDED TO SUB-ROUNDED SANDSTONE, ALMOST APPROACHING ARENACEOUS SHALE.

BLUE GREENISH, SOFT, FLAKY SHALE.

GREEN, WITH BROWN MOTTLING, HIGHLY CALCAREOUS, GRANULAR SHALE AND LENSES OF SILTSTONE. MANY CONE IN CONE STRUCTURES.
BLUE GREENISH, SOFT, FLAKY SHALE.

GREY TO DARK GREY, SILICEOUS SHALE CONTAINING A PROFUSION OF RADIOLARIA AND CONODONTS.

FIG. 8.—Detailed description of Moyers formation.

The basal siliceous shale is well exposed in the town of Moyers on the main Moyers-Kosoma State Highway, immediately east of the Moyers school house. This shale is ordinarily bluish green in color, but may vary from gray to dark gray. In places, rounded frosted sand grains occur as inclusions in this shale. In most parts of the Ouachitas thin lenses of chert conglomerates are intercalated in this shale and are well shown at the second type locality which was selected in Sec. 26, T. 1 S., R. 12 E. (Fig. 9). It is noteworthy that at many places in the mountains the siliceous shale is pierced by sandstone dikes.

The lithologic character of the Moyers differs in many respects from the underlying Tenmile Creek. The sandstones, also with a matrix of siltstone, have decidedly less argillite. The shale of the Moyers varies in color from blue to dark gray, green, olive-green, and greenish gray and the texture is flaky, splintery, and conchoidal. Cone-in-cone structures are common in this formation. About 470 feet above the basal siliceous shale are alternating greenish gray splintery shales with very thin layers of argillaceous silt varying to very fine sand, with quartzitic tendency. Though only a few feet thick at the type locality, these sediments reach a much greater development at other places.

All of the sandstones of the Moyers have irregular bedding planes which do not split. Many shreds of carbonized material are common in the sandstone; tiny flakes of muscovite are constant constituents.

In many parts of the Ouachita Mountains there occurs, about 200 feet below the top of the formation, a hard dark gray to black very fissile shale, in places siliceous, containing many minute quartz and chert grains. This shale is well exposed on the west side of the Tuskahoma syncline.

Several thin sections of the Tenmile Creek and the Moyers sandstones were made and all contain some feldspars and micas. Some grains appear to be weathered glass, which is suggested by its very low refractive index.

The description of thin sections of the lower Moyers siliceous shale follows.

Mostly clay, with considerable cryptocrystalline silica. Considerable fine angular silt and very rare angular sand grains. Very plentiful organic material, both black flakes and hazy red-brown areas. Many circular areas filled with secondary cryptocrystalline silica, which are replaced radiolaria and spores. In some areas, some fragments of red-brown material are left, characteristic of spores. Many sections show scattered spicules, some of which show cruciform types

General weathering character.—The basal siliceous shale weathers in many parts of the area to cream and purple color. At several places many layers exhibit a beautiful vari-colored rectangular or oval band-

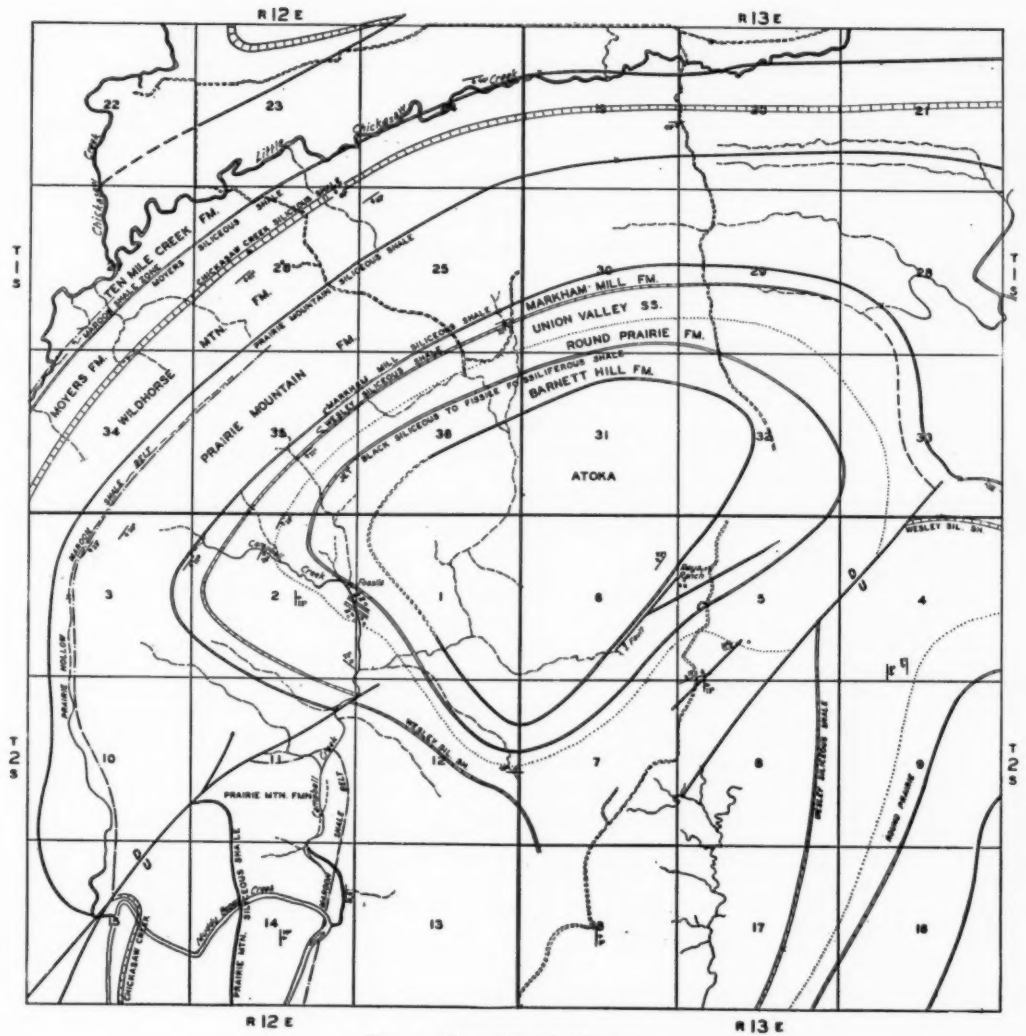


FIG. 9.—Map of Prairie Mountain.

ing effect. An excellent locality may be found near Pipe Springs Church in the SW. ¼, NE. ¼, Sec. 14, T. 3 S., R. 14 E. The sandstones of the Moyers weather to beautifully rounded masses and large shell-like pieces. The thinner sandstones exhibit a typical spheroidal weathering phenomenon in which the sandstone peels off like the layers of an onion.

Fauna.—The basal siliceous shale of this formation contains profuse radiolaria. Conodonts occur in profusion in seams throughout the shale. The upper sandstones contain many plant remains.

CHICKASAW CREEK SILICEOUS SHALE

Distribution.—This siliceous shale is the most prominent and consistent sedimentary body in the southern Ouachita Mountains. In most parts of the area it occurs a short interval below the first massive ridge-forming sandstone of the Jackfork group.

Thickness.—Its measurable thickness at the type locality approximates 270 feet. The exposures of this shale are covered by debris in many parts of the Ouachitas; however, its heavy float gives its approximate position. Where exposed its thickness is ordinarily between 80 and 270 feet except along the southern rim of the Tuskahoma syncline where locally it is only a few feet. This thinning was probably brought about by local disturbance.

Lithologic character.—The type locality for this shale was selected immediately south of Chickasaw Creek and is located in the center of the south line of the SW. ¼, 600 feet north of the section line of Sec. 7, T. 1 S., R. 13 E. The creek name is used as the formation name.

The lithologic character of the shale with its profuse white globular bodies, many of which were originally radiolaria, makes it easily recognizable wherever found. In the middle and upper part of this shale very thin intercalations of lenses of chert conglomerate are encountered, which, like the siliceous shales, are of very widespread distribution. The chert conglomerates are identical with those occurring in the basal siliceous shale of the Moyers. At the type locality the basal contact of the shale is not exposed, but at the second type locality it is splendidly shown.

SECTION AT TYPE LOCALITY

Feet	
0	Base not exposed
0–110	Dark gray, black, very fissile shale with gray thinly laminated fine-textured siliceous shale, containing thin seams of highly siliceous shale, some seams almost reaching a stage of chalcedony. The shale shows a varying degree of silicification
110–135	Intercalated lenses of chert conglomerate. The lenses ordinarily vary in thickness from 5 to 8 inches

Feet	
135–160	Shale as above
160–270	Covered, but due to the large amount of shale debris, it suggests the same material as below

Immediately above the shale, thin-bedded, fine subangular sandstones, containing profuse *Calamites* of Wildhorse Mountain age, are encountered. Detailed study of the chert conglomerate shows the following composition.

a. Buff extremely porous limestone—now highly leached
b. Dark brown material with white spherical bodies, suggesting siderite or volcanic ash, but may be radiolaria now completely destroyed
c. Three main kinds of chert
   1. Translucent white to grayish, with no markings
   2. Brownish chert with darker and lighter brown laminae. The type is probably silicified shale
   3. White to gray to yellow somewhat porous silica—apparently deposited as silicified limestone fragments

Due to the wide variety of chert it seems illogical to interpret the origin to silicification. At first glance in the field it suggests that originally it might have been a peculiar type of shale, which became silicified to a chalcedony, and during this process a shrinkage took place and thin fragments replaced angular material; in other words, the chalcedony became fractured and recemented. A refraction index test shows the conglomerate to consist chiefly of silica, which has a lower index than opal and a higher index than volcanic glass. Spherolites are characteristic of both secondary silica and tuffs, and the matrix seems to favor the latter.

The thin section of the chert conglomerate shows the following.

Chert and siliceous shale pebbles cemented with cryptocrystalline silica. Only one type of fracture visible, filled with finely crystalline silica. Some of the shale has siliceous spicules and is slightly calcareous. Some chert pebbles are apparently replaced limestones as evidenced by some calcite and few dolomite rhombs. Also a highly carbonaceous shale and carbonaceous material is laminated. At least half of the pebbles are silicified limestones as evidenced by dolomite rhombs (Pl. I, Figs. 3A and 3B)

The thin section of the siliceous shale shows the following.

Clay and silica. Wavy laminations are black carbonaceous material. Much red-brown organic matter. Numerous three-arm bodies, mostly broken, suggestive of radiolaria. Also perfectly round globular bodies always near red-brown bodies, not visible through cross-nickels, and which appear to be spores. It is likely that the round globular bodies are replaced radiolaria. Laminae are formed around both round globular bodies as well as spores, suggesting primary origin of round bodies (Pl. II, Fig. 1)

A second type locality for the Chickasaw Creek siliceous shale was chosen in the center of the W. ½, NE. ¼, NE. ¼ of Sec. 26, T. 1 S., R. 12 E. (Fig. 9). At that locality one encounters near the basal portion much black fissile shale with a few fossiliferous seams. Between the laminae the shale is literally covered with white globular bodies of radiolaria, and a few well preserved specimens were collected from this locality.

SECTION OF SECOND TYPE LOCALITY

Feet	
0	Basal contact well exposed
0–10	Black, fissile shale and intercalated dark gray and black siliceous shale. Profuse radiolaria—many conodonts in seams
10–66	Dark gray, black, highly siliceous shale and thin seams of black fissile shale. Profuse radiolaria throughout
66–68	Shale as above, and at base and top thin layer of gray argillaceous siltstone to medium angular quartzose sandstone, containing a profusion of round spherical bodies. Also many calamites noted
68–89	Alternating black fissile and highly siliceous shale
89–95	Very hard siliceous shale containing many conodonts and plentiful cruciform spicules. The shales also contain some shreds of carbonized material

A thin section was made of the sandstone which occurs about 68 feet above the base of this shale, and shows a groundmass of the following description.

Medium, angular to well rounded quartzose and quartzitic sandstone, some included plagioclase. Profuse, irregular shreds and plates probably of clay derived from volcanic ash. Many minute shreds within shreds and plates (Pl. II, Fig. 2)

The thin section of the black fissile shale underlying this sandstone shows the following.

Dark gray shale with very fine thin sponge spicules and plentiful globular areas, which are mostly shelled out, suggest: (1) primary concentration of organic silica, (2) extreme crushing. The filling of the globules exhibits both petrographic and structural similarity to ash (Pl. II, Fig. 3)

At many places in the mountains, generally near the middle of this shale, is a zone of 5 feet of chalcedonic rounded to subrounded masses which range in size from a few inches to 5 feet in diameter. The center of the mass ordinarily consists of black chert and the outer part has altered to a white to whitish gray dense siliceous mass. These chalcedonic masses have the appearance of being the result of concentration of silica. Associated with them are many well worn banded masses ranging in size from a few inches to about 2 feet in length. It is interesting to note that each band shows a varying degree of silicification. Examination of scores of the latter masses offers many suggestions of secondary silicified limestone bodies. No definite stand is taken on its origin; however, the latter interpretation is favored.

Another locality where these masses are well exposed and easily accessible is in a bank of a creek southwest of an abandoned saw mill,

EXPLANATION OF PLATE II

1.—Photomicrograph of Chickasaw Creek siliceous shale. Location same as Pl. I, Figs. 3A and 3B. Siliceous clay with many laminations of black carbonaceous material. (×14).

2.—Photomicrograph of sandstone in Chickasaw Creek siliceous shale, center, W ½, NE. ¼, NE. ¼, Sec. 26, T. 1 S., R. 12 E. Medium-grained, angular to subangular sandstone with siliceous cement.

3.—Photomicrograph of Chickasaw Creek siliceous shale. Location same as Pl. II, Fig. 2. Dark gray siliceous shale with sponge spicules and globular siliceous bodies. (×14).

4.—Photomicrograph of Markham Mill siliceous shale at Campbell Creek, T. 2 S., R. 12 E. Showing excellent gradation from clayey siltstone to fine-grained angular sandstone. (×14).

5.—Photomicrograph of conglomerate in Wesley siliceous shale, type locality, E. ½, SE. ¼, NW. ¼, Sec. 20, T. 1 N., R. 13 E. Chert and shale pebbles with some scattered sandstone grains. Both limestone pebbles and original limestone matrix have been altered to chert as shown at lower left of section. (×14).

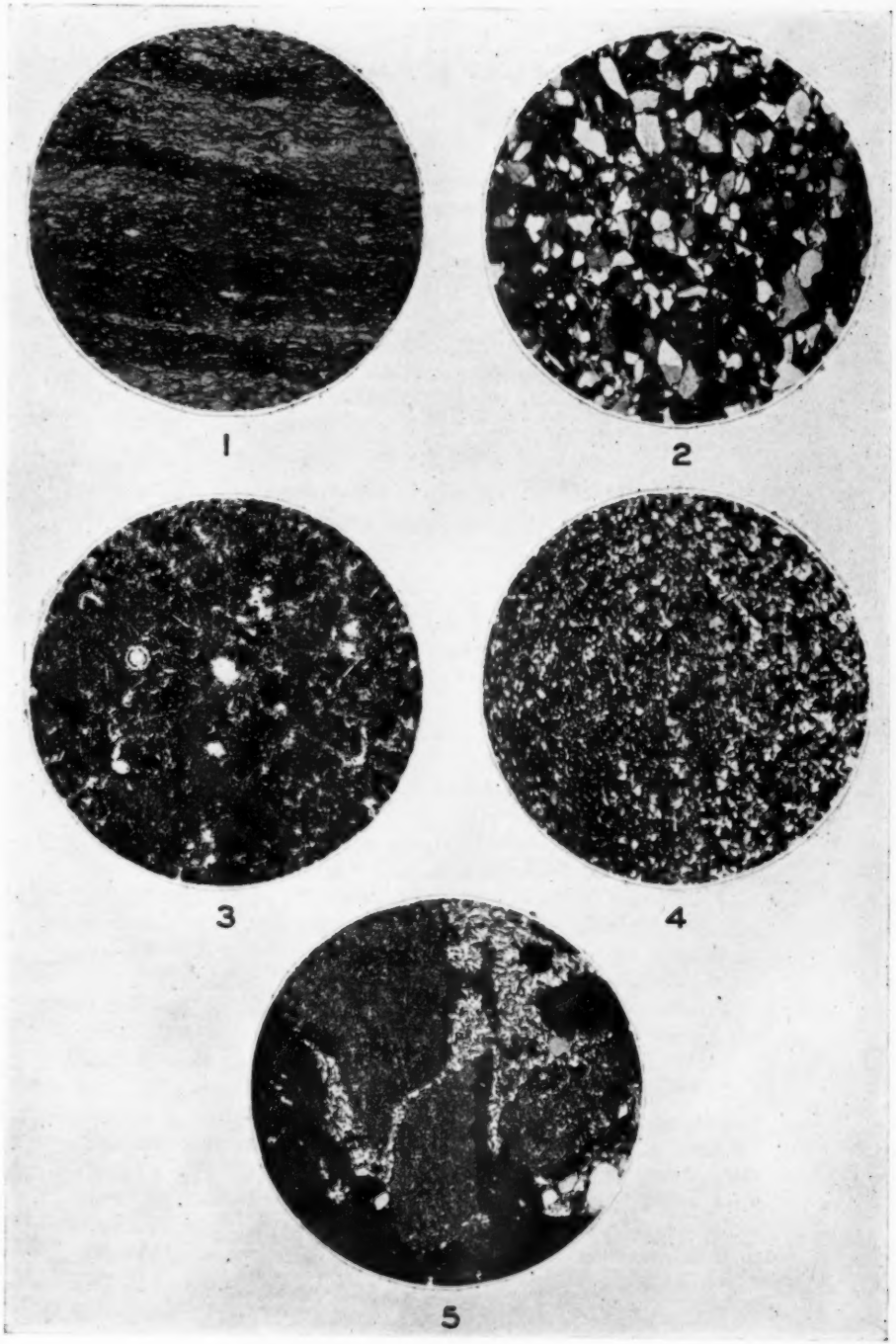


PLATE II

just off the county highway in the NW. ¼, NW. ¼, SW. ¼, Sec. 9, T. 2 N., R. 15 E.

Elsewhere in the mountains the zone can readily be mistaken for a boulder bed, and care must be exercised in the field in assigning these chert masses to the proper horizon.

General weathering character.—This siliceous shale weathers to hard platy masses, with some layers replaced completely by chalcedony.

Fauna.—The fauna of the Chickasaw Creek siliceous shale consists chiefly of radiolaria and conodonts. Spores are found commonly in seams. Brachiopods, chiefly Orbiculoidea, have been found in seams.

JACKFORK GROUP

The Jackfork group, a typically clastic deposit, is divided into four units of the rank of formations, namely, from the base upward, Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley.

WILDHORSE MOUNTAIN FORMATION

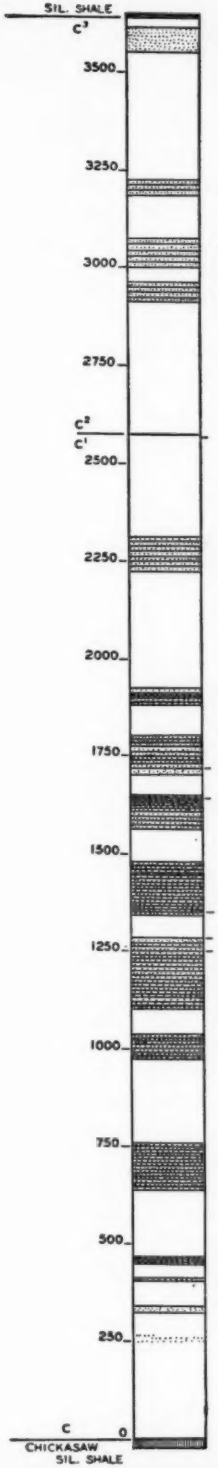
Distribution.—Near the base of this formation a massive ridge-forming sandstone is encountered, which forms escarpments up to 15 feet in height. Above this sandstone chiefly alternating shales and thin-bedded sandstones are found. It is noteworthy that these sandstones become massive along the western part of the mountains east of Black Knob ridge. The top of this formation is marked by a very massive solid sandstone which caps the main mountain-forming part of the area. Along the southern rim of the Tuskahoma syncline it forms a very massive vertical cliff, and was measured at several places where it attained a thickness of 60 feet.

Thickness.—The thickness of this formation at the type locality is, in general, more than 3,550 feet. Along the western border of the mountain a very conspicuous thinning may be observed, so that the entire thickness may not exceed 1,000 feet.

Lithologic character.—The type locality for this formation (Fig. 6) was chosen in Wildhorse Mountain from which its name was taken, and is located north of the town of Moyers in T. 2 S., R. 16 E., and is indicated on the map by the letter *C* (for detail description see Figure 10). The massive bed which occurs near the base consists of tan-colored, fine to coarse, rounded to subangular argillaceous sandstone. About 62 feet above this basal sandstone occurs 8 feet of sandstone, which is green with maroon mottling, very hard, very fine to medium, with subrounded to subangular grains. The matrix is largely siltstone and some streaks contain many coarse grains. Above this

WILDHORSE MOUNTAIN FORMATION

SEE MAP FIG 6 LINE C



VERY MASSIVE, TAN, FINE TO COARSE, ROUNDED TO SUBANGULAR SANDSTONE
BASAL PORTION CONSISTS OF SILTSTONE TO FINE SANDSTONE
MOST PROMINENT CLIFF FORMER IN THE MOUNTAINS.

THIN BEDDED, GREENISH, ARGILLACEOUS SILTSTONE TO FINE SANDSTONE.

MASSIVE, TAN, ARGILLACEOUS SILTSTONE TO FINE SANDSTONE, WITH BLEBS OF GREEN ARGILLITE. WEATHERS TO VERY LARGE SHELLS AND LARGE ROUNDED BOULDERS.

MASSIVE, TAN, ARGILLACEOUS SILTSTONE, WITH SOME INCLUDED MEDIUM GRAINS

COVERED.

< WILDHORSE CREEK.

COVERED.

MASSIVE, VERY FINE TO MEDIUM, SUBROUNDED TO SUBANGULAR, LIMONITIC SANDSTONE.

< CREEK; OLIVE GREEN SHALE.

MASSIVE AND THIN BEDDED, WHITE, FINE TO COARSE, ROUNDED TO SUBANGULAR, CALCAREOUS SANDSTONE; COARSE ROUNDED GRAINS PREDOMINATE. IRREGULAR CASE HARDENING.

MASSIVE AND THIN BEDDED, FINE TO COARSE, ROUNDED TO SUBANGULAR, ARGILLACEOUS SANDSTONE.

VERY FINE TO COARSE, ROUNDED TO SUBANGULAR, HIGHLY ARGILLACEOUS SANDSTONE. MATRIX MOSTLY SILTSTONE.

SMALL CLIFF ON NORTH SIDE OF CREEK) GREENISH, VERY FINE TO MEDIUM, SUBROUNDED TO SUBANGULAR SANDSTONE. MATRIX MOSTLY SILTSTONE.
THIN BEDDED, VERY FINE TO COARSE, SUBROUNDED TO SUBANGULAR SANDSTONE

THIN BEDDED, HARD, VERY FINE TO MEDIUM, SUBANGULAR, ARGILLACEOUS, LIMONITIC SANDSTONE; ORIGINALLY CALCAREOUS, CONTAINING MANY CALAMITES; BOTTOM SURFACE WEATHERS TO BRIGHT RED, AND HAS MANY BEAUTIFUL BEACH CUSPS.

VERY MASSIVE, ARGILLACEOUS, VERY FINE TO MEDIUM, SUBANGULAR SANDSTONE. MATRIX MOSTLY SILTSTONE, MANY INCLUDED WHITE SPECKS, SOME MICA; WEATHERS TO LARGE ROUNDED BOULDERS, AND PEELS OFF IN LARGE SHELLS.

VERY MASSIVE, GREENISH, HIGHLY ARGILLACEOUS, VERY FINE TO COARSE SANDSTONE; WEATHERS TO LARGE ROUNDED BLOCKS.

GREENISH, ARGILLACEOUS, VERY FINE TO COARSE, ROUNDED TO SUBANGULAR SANDSTONE; WEATHERS TO LARGE SHELLS. UPPER PART EXPOSED IN CREEK CONTAINS MANY INCLUDED, VERY LARGE, ROUNDED TO SUBROUNDED QUARTZ GRAINS.

THIN BEDDED, GREENISH, ARGILLACEOUS SILTSTONE, WITH QUARTZITIC TENDENCY; THIS SANDSTONE IS FINELY LAMINATED, AND WEATHERS TO VERY THIN SHELLS; MANY BEACH CUSPS AT BOTTOM SURFACE.

COVERED.

THIN BEDDED, VERY FINE TO MEDIUM, SUBANGULAR, LIMONITIC SANDSTONE, ORIGINALLY CALCAREOUS, CONTAINING MANY CALAMITES. MANY BEACH CUSPS AT BOTTOM SURFACE.

SOIL COVER.

THIN BEDDED, PLATY, GREEN AND MAROON MOTTLED, VERY FINE TO MEDIUM, SUBROUNDED TO SUBANGULAR, ARGILLACEOUS SANDSTONE. THIS SANDSTONE HAS BEAUTIFUL BEACH CUSPS AT BOTTOM SURFACE, AND IS EXTENSIVELY QUARRIED AS BUILDING STONE.

VERY HARD, GREEN WITH MAROON MOTTLING, VERY FINE TO MEDIUM, ARGILLACEOUS SANDSTONE.

VERY MASSIVE, FINE TO COARSE, ROUNDED TO SUBANGULAR, ARGILLACEOUS SANDSTONE CLIFF FORMER. WEATHERING PHENOMENA SEE FIG. 11.

MASSIVE, TAN, HIGHLY ARGILLACEOUS, SILTY TO COARSE SANDSTONE, OVERLAIN BY THIN, PLATY, ARGILLACEOUS SILTSTONE WITH WAVY LAMINAE AND INTERCALATED SHALE

FIG. 10.—Detailed description of Wildhorse Mountain formation.

member, alternating shales and thin-bedded sandstones predominate. The sandstones are green and maroon mottled, and vary from silt as a matrix to medium, subrounded to subangular, argillaceous sandstone. The bottom surfaces of this sandstone are smooth, with a splendid development of elongate protuberances which are interpreted as beach cusps. This sandstone is extensively quarried as an ornamental building stone, and was used on a part of the Moyers schoolhouse. The most striking feature of most of the Wildhorse Mountain sandstones is the uniform, thinly bedded character. The shales of this formation are soft and flaky, and an olive-green color predominates. Cone-in-cone structures have been found at several horizons. At the top is a massive bed of sandstone which forms a ridge or bench.

A second type locality, easily accessible, was selected in Secs. 25 and 26, T. 1 S., R. 12 E. (Fig. 9).

General weathering character.—The basal sandstones of this formation weather to irregularly rounded masses, and in some places in the mountains are difficult of differentiation from the underlying Moyers sandstone. Some portions of the lower sandstones show interesting weathering phenomena (Fig. 11). Due to differential weathering a rectangular pattern is produced which exhibits within it a beautiful etching effect. The thin-bedded sandstones ordinarily break off in square to elongate angular slabs and readily weather to a deep red color. The weathering effect of the massive upper member of the Wildhorse Mountain is analogous to that of the overlying Prairie Mountain formation, later discussed.

Fauna.—The sandstones of the Wildhorse Mountain contain many plant fossils. *Sigillaria* and *Calamites* are very common.

PRAIRIE MOUNTAIN FORMATION

Distribution.—A very thin but widespread siliceous shale marks the base of this formation in most parts of the Ouachita Mountains. The succeeding massive sandstones form very prominent ridges in the area from Round Prairie to the state line. The variegated maroon and green shale belt, which occurs approximately 450 feet above the base of this formation, is of widespread distribution. Since this zone is of stratigraphic importance in surface mapping it is proposed to apply the name Prairie Hollow to this member.

Thickness.—In the Tuskahoma syncline this formation aggregates a thickness of approximately 4,300 feet. The massive character of the sandstones diminishes within a short distance westward along the western border of the area, and the shaly member appears to predomi-

nate. Also, a very conspicuous thinning of the entire formation may be observed. In the Prairie Mountain, T. 1 S., R. 12 E. (Fig. 9), the thickness approximates 1,350 feet. The basal siliceous shale, which is very widespread, ranges from 1 to 2 feet in thickness.

FIG. 11.—Weathering phenomena of Wildhorse Mountain sandstone. One-half natural size.

Lithologic character.—The type locality of this formation was chosen in Prairie Mountain, from which its name is taken, and is located in the center of Sec. 25, T. 1 S., R. 12 E. (Fig. 9). The siliceous shale which occurs at the base is dark gray to gray in color and is characterized by its profuse carbonized plant remains. The siliceous shale is succeeded by mostly massive, fine to coarse, subangular sandstones and intercalated shales. The variegated maroon and green shale belt is well exposed in Prairie Hollow in Ts. 1 and 2 S., R. 12 E. (Fig. 9) whence it received its name.

The thin sections of the basal Prairie Mountain siliceous shale show the following.

Dark gray fine siliceous shale with rare scattered angular fairly even silt. Very numerous spines and spicules and other siliceous organic fragments. Also radiolaria spines

The weathered maroon to red-brown siliceous shales are described as follows.

Dark red-brown fine siliceous shale with siliceous spicules and spines and other organic matter. Many blebs of very dark brown opaque material, probably hematite

General weathering phenomena.—The siliceous shale weathers to bluish gray and gray color; very commonly it weathers to tan, yellow-

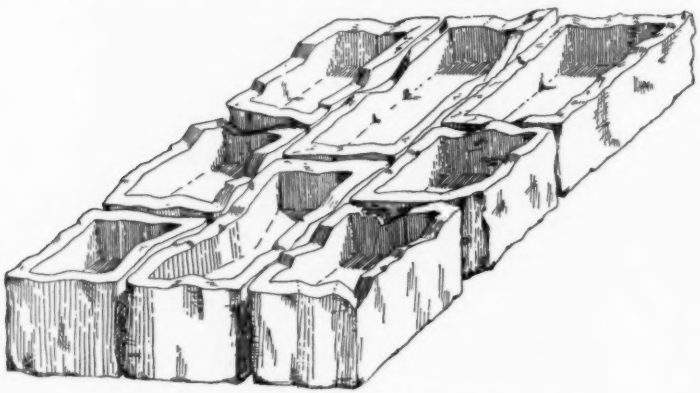


FIG. 12.—Weathering phenomena of Prairie Mountain sandstone. One-third natural size.

ish, or maroon mottling; however, almost all of these portions are free of the carbonized material. The surface weathering phenomena of the sandstones are exceedingly interesting. Differential weathering agents had a considerable effect on most, if not all, of the Prairie Mountain, as well as on the upper massive member of the Wildhorse Mountain. This effect produced masses with a remarkably arranged parallelism resulting in a beautiful rectangular pattern. It is important to note that this weathering effect has not been observed in any other formation and thus may be used as a physical criterion; however, in its minor stages of development one should exercise the greatest care.

Several stages of history are observed on many of the sandstones. 1. Rectangular lines penetrate the coarse, weathered surfaces of the sandstones in a parallel arrangement. This remarkable pattern is interpreted to be the result of rectangular joint planes. Infiltration of iron-bearing solution and the limonitic cementation of the joint planes

FIG. 13.—Fossil plant (*Lepidodendron*) of Prairie Mountain formation. SE. ¼, SE. ¼, Sec. 4, T. 2 S., R. 16 E. Two-thirds natural size.

resulted in case-hardening of the surfaces. 2. Further weathering processes deepened the intervening areas between the rectangular joints, because the case-hardened border of the rectangular blocks was strongly resistant to weathering, and the slightly cemented central part produced a conspicuous hollowed-out space. 3. Finally, complete erosion of intermittent areas between rectangular lines has left rectangular box-like remnants (Fig. 12).

Fauna.—The sandstones are characterized by plant fossils, for example, *Sigillaria*, *Calamites*, and *Lepidodendron* (Fig. 13).

MARKHAM MILL FORMATION

Distribution.—The Markham Mill formation consists predominantly of shale with some thin sandstones. It is very widespread in distribution in the entire Ouachita Mountains and is easily recognized due to the very massive overlying Wesley siliceous shale.

Thickness.—The thickness of this formation varies from 220 to about 500 feet. At the type locality it measured about 400 feet. A very conspicuous thinning of the Markham Mill formation occurs in the area between the Ti Valley and the Windingstair fault zones. In this area the Markham Mill formation, exclusive of its basal siliceous shale, consists locally of only 10 feet of sandstone. The basal siliceous shale ordinarily measures about 20 feet in most parts of the mountains.

Lithologic character.—The type locality for this formation is in the NE. cor., SW. $\frac{1}{4}$, Sec. 21, T. 2 S., R. 14 E. (Fig. 14). The name is taken from a saw mill, Markham Mill, which has been in operation more than 20 years. A second type locality was chosen in Sec. 2, T. 2 S., R. 12 E., along Campbell Creek (Fig. 9). This was first considered as the type locality but, unfortunately, no name was available in this area. Here the formation is well developed and is easily accessible.

The basal division of the Markham Mill formation is composed of siliceous shale and consists of 15–20 feet of hard, platy to blocky, dark gray beds. This shale is commonly characterized by inclusions of black carbonized plant fragments, and its color ordinarily is gray to dark gray with much black mottling. In some places in this shale are intercalations of thin seams of gray argillaceous silty siliceous shale and thin laminae of white siltstone. The middle and upper parts of the formation are thin-bedded sandstones. They vary from silts to beds composed of fine subangular sand grains. The upper Markham Mill beds are sandstones which ordinarily contain large milky white quartz grains. These quartz grains are widespread throughout the area.

Near or at the base of the Markham Mill siliceous shale at Prairie Mountain and vicinity are lenses of cherty sandstone conglomerate. The conglomerate is coarser northward, becoming boulders in the frontal part of the mountains. These boulders were dropped into the sea during the time the basal siliceous shale was laid down.

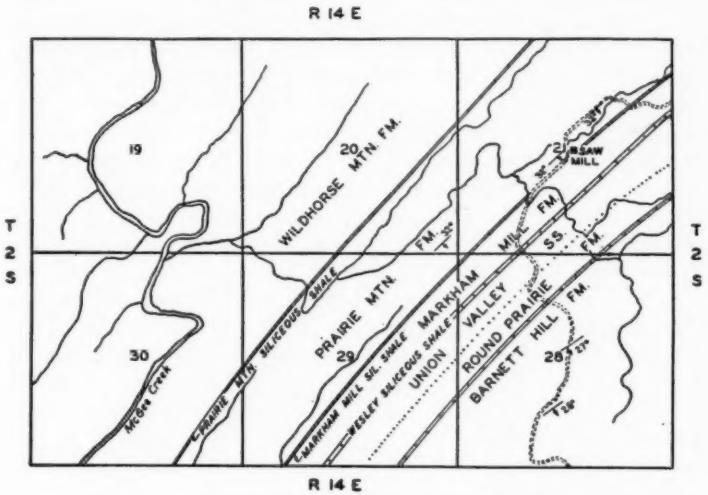


FIG. 14.—Map showing type locality of Markham Mill formation.

The thin section of the Markham Mill siliceous shale at Campbell Creek in T. 2 S., R. 12 E., is described as follows.

Silty shale to siltstone and fine sandstone, with some degree of bedding. It has many shreds and flakes probably of volcanic material. Silicification varies, some areas showing more than others. Few sponge spicules (Pl. II, Fig. 4)

About 300 feet north of this location the siliceous shale has the following description.

Very fine, green, even-textured siliceous shale, containing abundant spicules both large and small, parallel with bedding

General weathering phenomena.—The basal siliceous shale weathers readily, the color is light dull pink, grading into deep maroon to dark gray mottling. The shale weathers readily to large slabs, ordinarily rectangular in outline, making it easily identifiable. The sandstones weather in rather irregular surfaces.

Fauna.—The thin sandstones of the Markham Mill contain many plant fossils, for example, *Sigillaria* and *Calamites*.

Erratics.—As mentioned previously, the Markham Mill siliceous shale contains erratic boulders in the frontal Ouachitas.

WESLEY SHALE

Distribution.—This siliceous shale, also, is one of the best developed and most widespread of diagnostic shales in the Bendian stratigraphic column. It is easily recognized and has been found at many localities in the Ouachita Mountain area. Exposures in normal sequence are particularly plentiful in Round Prairie in Ts. 1 and 2 S., R. 12 E., and in the mountains east of McGee Creek in Ts. 1 and 2 S., R. 14 E. Along the frontal belt and in the Ti Valley area exposures are irregularly scattered due to complex faulting. The best exposures are found at the type locality in T. 1 N., R. 13 E.; N. ½, Sec. 18, T. 1 S., R. 13 E.; and in a creek bank in the center of Sec. 9, T. 2 N., R. 15 E. Along the Choctaw fault zone, shale of Wesley age is found everywhere in normal contact with the Caney shale of Chester age. This also applies to the various windows, for example, at Pine Top schoolhouse and Wesley.

Thickness.—The thickness of this shale at the type locality is about 500 feet. The exposures of this shale also are covered by débris in many parts of the mountains, although its heavy float shows its approximate position.

Lithologic character.—The type locality for this shale was selected southwest of the village of Wesley in the E. ½, SE. ¼, NW. ¼, Sec. 20, T. 1 N., R. 13 E. (Fig. 15). At this locality the shale exhibits a splendid development. The shale is also well exposed on Campbell Creek in Sec. 2, T. 2 S., R. 12 E. (Fig. 9).

The Wesley siliceous shale can easily be confused with the Chickasaw Creek siliceous shale, because of the many intercalations of lenses of chert conglomerate. At some places in the mountains there is little or no difference between the conglomerates found in these two shales. However, most of the Wesley conglomerates appear to be distinct and seem to be limestone conglomerates which have changed to chert. They also contain many included shale and siliceous shale pebbles, which have not been reworked. Also some sand grains are noted around chert pebbles; fragments of cemented pieces of sandstone occur here and there. A characteristic is that the chert pebbles are dense and featureless and do not show any markings of any kind. The bond is highly siliceous between the pebbles, and a logical assumption is that the limestones, which were originally porous, were easy prey to silicification. The conglomerate shows many small and many large cavities, showing that some of the pebbles have been dis-

solved. A few cavities were observed which left behind only the spicules of sponges. Accordingly, it appears obvious that one may interpret these facts as indicating three stages of history: (1) deposition of

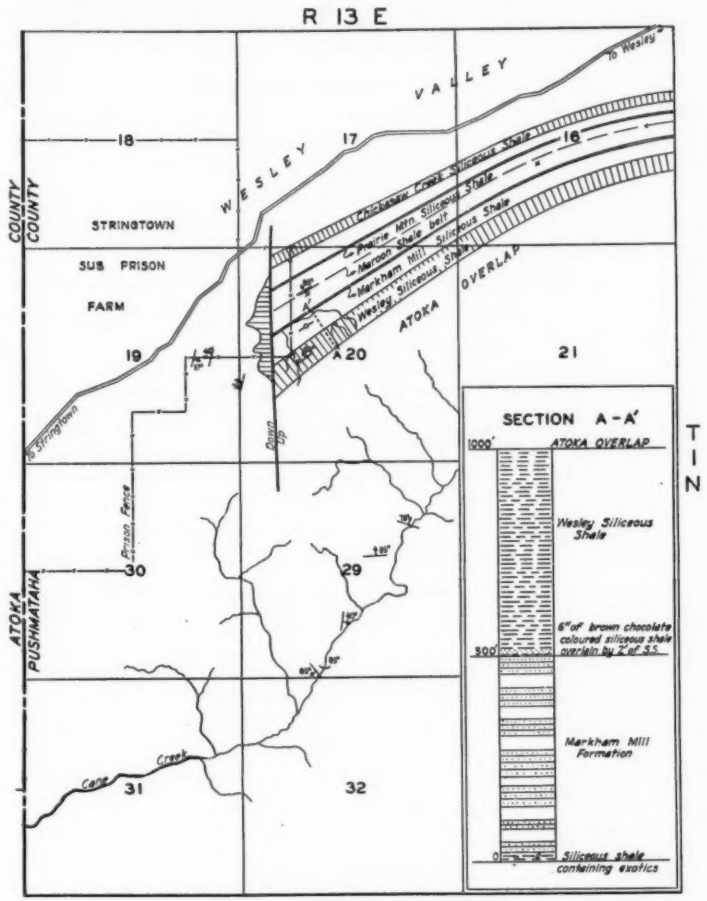


FIG. 15.—Map showing type locality of Wesley siliceous shale.

limestone conglomerate; (2) silicification, although in some places silicification was not complete; (3) after that, solution.

An interesting thin section of the chert conglomerate from the type locality shows the following.

Limestone conglomerate, changed to chert, consisting of excellent pieces of Woodford siliceous shale with many spores and sponge spicules. Between chert pebbles are sand grains, fine to coarse and cemented with silica. It furnishes an excellent illustration of fractures, later filled with silica, which cross both pebble and cement, evidencing that the chert was fractured after deposition. One piece shows crushing between two other pieces; the piece which is crushed is a siliceous shale with considerable organic matter, pieces on both sides consist of a hard chert. The crush zones are fractures, now filled with secondary silica (Pl. II, Fig. 5)

The thin sections of the siliceous shale from the type locality show the following.

Clay with few included replaced large spines. Some sponge spicules and very rare fine silt, which suggest altered volcanic material

Other thin sections consist of the following.

Clay with many spines and fine, angular, poorly sorted sand and silt grains. Both spines and sponge spicules are siliceous. Profuse organic matter

At and near the top of the Wesley siliceous shale, lenses of conglomeratic sandstones are encountered, well shown in T. 1 S., R. 12 E. A thin section of this conglomerate has this description.

Conglomeratic sandstone, pebbles consisting of fine chert, some of them limestone pebbles, which probably became silicified. Some black chert pebbles with rounded siliceous globules, suggesting silicified spores or radiolaria. Few pebbles of gray translucent chert with abundant sponge spicules. The pebble was a chert before it was deposited in the sand matrix

Matrix: fine sandstone with strong development of secondary re-crystallization of the quartz grains, containing some argillaceous streaks

Another thin section was made of this conglomerate from the same locality, and has the following description.

Medium-grained angular sandstone with secondary silica cement and chert pebbles, most of which seem to be siliceous shale. This sandstone contains many wisps and flakes which appear to be volcanic ash. Few feldspars noted

The most diagnostic feature of the Wesley siliceous shale is the presence of large rounded to subrounded chalcedonic masses which are irregularly intermixed in the shale matrix. These chalcedonic masses resemble the rounded to subrounded masses in the Chickasaw Creek and also consist of dark gray to black chalcedony with the color becoming darker toward the center. The Wesley chalcedonic masses show clearly that they are primary in origin.

Along the Choctaw fault zone, the Wesley shale is lithologically like Arbuckle Mountain in character, being a dark gray to black splintery shale, containing a profusion of siderite nodules and concretions. The same lithologic character prevails in the exposed windows in the frontal belt. However, in some places siliceous shales are found intercalated. An excellent example may be seen at Pine Top schoolhouse, where the basal part of the Wesley contains many siliceous layers, with some completely developed to chalcedony. The siliceous character of the Wesley shale not only prevailed in the Ouachita

Mountains, but also spread westward into the Arbuckle Mountain region, as shown just west of Ravia in the SW. ¼, NW. ¼, Sec. 3, T. 4 S., R. 5 E.

Since the siliceous character of the Wesley occurs in the frontal part of the Ouachitas, where Arbuckle facies prevails, as well as in the Arbuckle Mountains, the writer sees no valid reason for restricting the name Wesley to the Ouachitas only.

Fauna.—The non-siliceous shale layers contain foraminifera, of which the most plentiful are *Hyperammia*, *Cornuspira*, *Bigenerina*, *Haplophragmoides*, *Agathammina*, and *Sherbonites*. In many of the siliceous masses or concretions aforementioned one may find ammonoids encased. The largest ammonoid so far found has a diameter of 1,470 millimeters.

Correlation.—The Wesley siliceous shale is a correlative of most of the shale heretofore called "Pennsylvanian Caney." In the Arbuckle Mountains it occurs between the Union Valley sandstone and the Chester Caney shale, and in the Ardmore basin it occurs between the Rod Club sandstone and the latter shale. This shale body attains a tremendous thickness in the Ardmore basin and since it is an important, recognizable lithologic and paleontologic unit of widespread distribution in the Mid-Continent it deserves formational rank. Therefore, the name Wesley shale has been proposed.

MORROW SERIES

The Morrow geosyncline is an entirely new base dynamically, which disrupted the old structural lines at its initiation. The Morrow deposits, which in most parts of the Ouachitas fail to give a complete depositional record, present some exceedingly intricate stratigraphic and paleogeographic problems. Evidently numerous oscillations of the sea floor caused individual members to be erratic in distribution and character. Particular reference is made to the basal intercalated conglomerates and fossiliferous fragmental limestones.

SOUTHERN OUACHITAS

UNION VALLEY FORMATION

The equivalent of the Hale formation of northwestern Arkansas has been recognized in Oklahoma for many years. In the area north of the Arbuckle Mountains this unit is known to the oil industry as the "Cromwell" or the Union Valley sandstone.[6,7] In the Ardmore

[6] R. V. Hollingsworth, "The Union Valley Sandstone," abstract, *Pal. Soc. America* (December, 1933).

[7] Bruce H. Harlton, *op. cit.*, p. 1024.

basin its equivalent is now known to include the Lake Ardmore and the Overbrook sandstones and the Rod Club sandy members of the Springer.

The Union Valley formation was the initial deposit of Morrow time. The unconformity at the base of the Union Valley, which in the Ouachitas is marked by the Stapp conglomerate, indubitably is the proper horizon on which to draw the base of the Morrow.

Distribution.—This formation is a very widespread deposit and the sandstones in most areas make up ridges of moderate relief. Scattered exposures are found immediately south of the Choctaw fault from the vicinity of Limestone Gap to the Arkansas state line. In Prairie Mountain it is well exposed.

Thickness.—Where exposed in normal sequence, the thickness of this formation is uniform and approximates 360 feet at most places in the mountains.

Lithologic character.—The typical exposure of the Union Valley in the Ouachita Mountains is in Sec. 36, T. 1 S., R. 12 E. It consists of gray to dark gray shale and intercalated massive and thin-bedded greenish yellow, fine to medium subangular sandstone, ordinarily with some included mica. In texture, the thin-bedded sandstones commonly vary from silt to fine subangular grains. Intercalations of fine to medium-coarse fossiliferous limonitic sandstone containing a profusion of crinoids and calamites (Figs. 16 and 17) are common. Some of these fossiliferous horizons are found to consist of brown highly hematitic arenaceous siliceous limestone with many small pockets of green argillite scattered throughout. The sand grains are fine to coarse, rounded to subangular, and break through on a fracture. In some parts of the area, these zones consist of a brown highly leached fossiliferous matrix and thin sections show the following composition.

Siderite nodules changed over to hematite. The part which is sandy became silicified, as shown by sand fractures. Sandy part contained originally much siderite and also became replaced by silica. Some vugs originally contained fossils which became dissolved out and later filled with silica. The clay pebbles are oriented with the long axes parallel, indicating that the formation was deposited in water. The great amount of siderite present unquestionably indicates still-water deposition

General weathering character.—The sandstones of the Union Valley weather to gray, maroon, and yellow in color. There is ordinarily no zonal weathering, but case-hardening by silica is common. The bottom surfaces have reniform, elongate protuberances, which are considered beach cusps. The rectangular weathering patterns of the more massive sandstones are similar to those of the Prairie Mountain.

Fauna.—The megascopic faunal zones in this formation occur in a

FIG. 16.—Fossil plant (*Calamites*) of Union Valley sandstone, center, W. ½, NE. ¼, SE. ¼, Sec. 31, T. 1 S., R. 14 E. Seven-eighths natural size.

FIG. 17.—Fossil plant (*Calamites*) of Union Valley sandstone, center, W. ½, NE. ¼, SE. ¼, Sec. 31, T. 1. S., R. 14 E. Two-thirds natural size.

soft sandy matrix, which was originally highly calcareous, in some places approaching a fragmental limestone. Ordinarily the shells have been dissolved, leaving only the exterior and interior mold, which commonly preserves details of structure and surface ornamentation. Many species of the Union Valley are forerunners of the upper Bendian, the vertical range of which continued with occasional intermissions through hundreds of feet upward in the section, but other species are confined to narrow vertical limits. The characteristic species offer practically no uncertainty and no difficulty in identifying these Ouachita exposures with the Hale formation of northwestern Arkansas, and its western exposures in the Arbuckle Mountain area. Some of the diagnostic genera are *Aviculopecten*, *Bellerophon*, *Conularia*, *Gastrioceras*, *Productus*, *Orthoceras*, and *Griffithides*.

STAPP CONGLOMERATE MEMBER

The conglomerate at Stapp, Oklahoma, has been classified hitherto as the base of the Atoka. This assignment was made mainly on the mistaken belief that the overlying sandstones were Atoka in age. The more recent discovery of several fossil zones at Stapp within the conglomerate and immediately above revealed the true position of this conglomerate as a member of the Union Valley formation.

Because of the immediate need of evidence showing the distinctness of this conglomerate and the subsequent important rôle it played, as outlined in the following pages, it is proposed to use the term Stapp for this conglomerate. It is excellently exposed in the Kansas City Southern Railway cut, one mile south of Stapp in the SW. ¼, SW. ¼, Sec. 7, T. 3 N., R. 26 E. (Fig. 18). The constituent masses of the conglomerate consist of rounded pebbles and boulders of chert and limestone, ranging from a fraction of an inch to large masses 3 feet in diameter. Due to its massive, very coarse, slightly cemented character, bedding planes are wholly absent. Several zones of cross-bedding may be found in this conglomerate by intercalations of thin lenses of sandstone and conglomeratic sandstone. Near the top a very thin layer of black shale is encountered, which in turn is overlain by very coarse, loosely consolidated conglomerate. The shales and sandstones immediately above the conglomerate in streaks are highly fossiliferous.

Boulders of the same conglomerate with masses of fragmental fossiliferous limestone still attached to the conglomerate and carrying the same fauna, are found in the Round Prairie bouldery shale. Also large slices of this conglomerate carrying identical fauna have been found in the road cut on State Highway 2 in the SE. ¼, SW. ¼, SW. ¼,

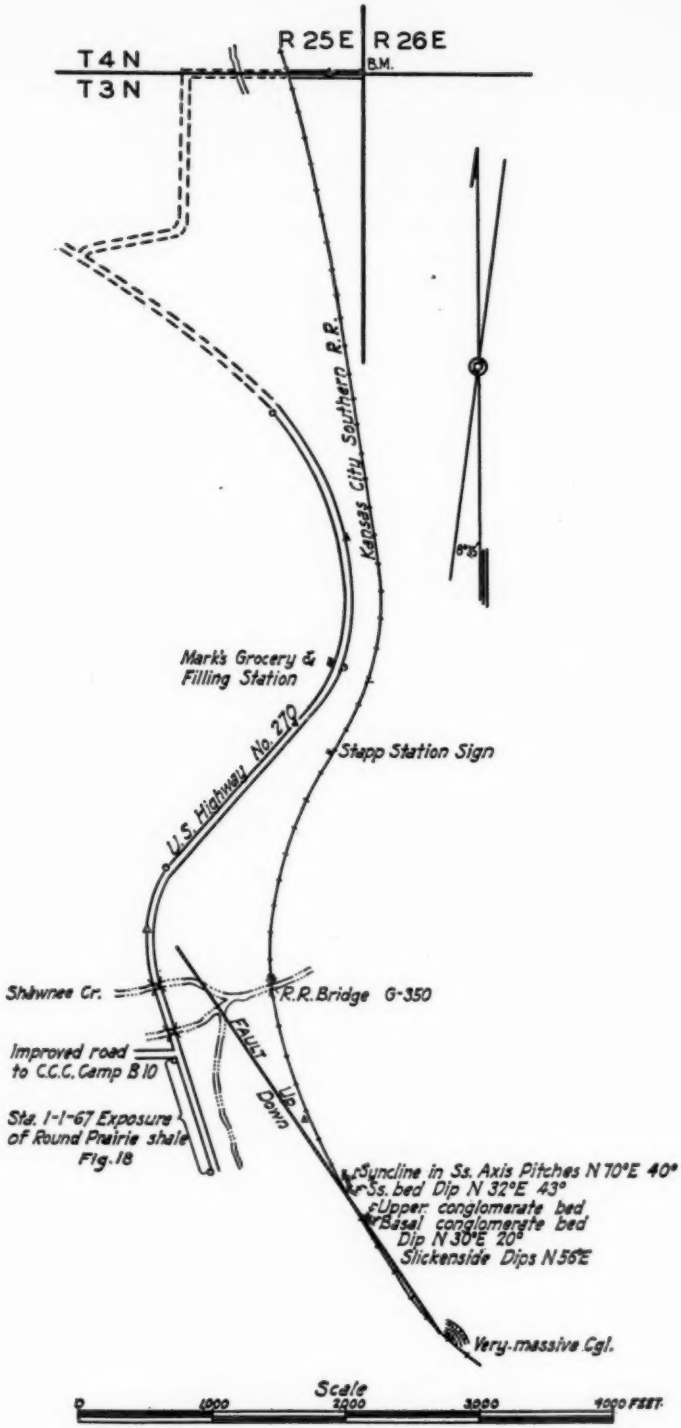


FIG. 18.—Plane-table survey of the Stapp area by Thomas A. Hendricks and Bruce H. Harlton.

Sec. 27, T. 4 N., R. 19 E., and in a creek about 100 yards east of the same highway at another locality about 0.4 mile north of Talihina Junction in the NE. ¼, NW. ¼, Sec. 14, T. 3 N., R. 19 E. At the latter locality the conglomerate is shown exposed in a friction carpet and is still in contact with a fossiliferous fragmental limestone. The well rounded character of the boulders and pebbles in this conglomerate indicates transportation by water, manifesting that the contributing land was high. The large worn boulders, as large as 3 feet in diameter, in this conglomerate suggest that the land must have had locally steep gradients.

It seems inconceivable that the torrential deposits of the coarse clastics in this conglomerate were a mere local phenomenon because, as mentioned previously, the conglomerate is found at many places both in the friction carpet and in the Round Prairie bouldery shale. It appears logical from the evidence at hand that several land barriers of great consequence were in existence during the time the conglomerate was laid down. The time during which the boulders and pebbles were accumulated also must have been of relatively great duration because most, if not all, of the masses are well worn and rounded.

CONGLOMERATE AT BOLES, ARKANSAS

The age of the conglomerate at Boles, Arkansas, was designated by the writer[8] in 1934 as basal Springer on the evidence of microfaunas found in the black shales at and near the contact with the conglomerate. Additional paleontological evidence obtained from the shale underlying the conglomerate corroborates the conclusions then presented. The Stapp conglomerate greatly resembles the conglomerate at Boles and undoubtedly is closely related to it. Accordingly the taxonomic boundary of the conglomerate may be placed at the opening of Union Valley (Morrow) time.

The excellent exposures of the Wesley siliceous shale near the center of Sec. 9, T. 2 N., R. 15 E., on the creek bank yielded fauna identical with those of the black shales underlying the conglomerate at Boles, Arkansas. An excellent exposure at a recently constructed fish dam at that locality is easily accessible.

ROUND PRAIRIE FORMATION

Distribution.—This formation is exposed at many places south of the frontal part of the mountains, some of the best exposures being in the Frisco Railway cut at Compton and Lamberson Spur, in the road cut at Stapp, Oklahoma, in a creek about 0.4 mile north of Tali-

[8] Bruce H. Harlton, *op. cit.*, p. 1045.

hina Junction in the NE. ¼, NW. ¼, Sec. 14, T. 3 N., R. 19 E., and in Round Prairie. Miser[9] and the writer[10] described this formation in detail in 1934 under the old name, Johns Valley shale.

The gray and black bouldery shales exposed in Johns Valley, in T. 1 S., R. 16 E., were thought for many years to represent one formation, and the name Johns Valley was applied to them. Later this name was extended to apply to all similar bouldery shales of Bendian age in the Ouachitas. It is now recognized, however, that in Johns Valley are found exposures of three kinds and ages of shales, namely, Chester (Caney), Pushmataha (Wesley), and Morrow (Round Prairie). Due to the heterogeneous mixture of these bouldery shales in Johns Valley, it can no longer be recognized as a type locality of any formation; therefore, the name Johns Valley shale has been abandoned as a valid formation name. The exposures referred to as Johns Valley shale in the paper by the writer in 1934, are correlated definitely with the Round Prairie formation, the Wesley siliceous shale, and the Markham Mill siliceous shale.

The Round Prairie bouldery shales have been brought to the surface along major fault zones at many places in the Oklahoma Ouachitas. Due to its position, parallel with steeply dipping thrust faults, it was protected from the agents of erosion.

Thickness.—The Round Prairie formation ordinarily varies from 400 to 600 feet in thickness. In some places, the thickness is more than 800 feet.

Lithologic character.—At the type locality in the NE. ¼, NE. ¼, SE. ¼, Sec. 2, T. 2 S., R. 12 E. (Fig. 9) the section includes a lower boulder bed, which overlies the Union Valley sandstone, separated from an upper bouldery shale by two or three beds of sandstones. Some of these sandstones are highly calcareous and fossiliferous and are approximately 25 feet apart. The middle sandstone in most places approaches an arenaceous limestone. The upper bouldery shale is overlain by 10–15 feet of jet black, fissile, fossiliferous shale, locally siliceous, with seams completely developed to chalcedony. This shale, as well as the underlying boulder beds, is excellently exposed in the NW. corner of T. 3 S., R. 14 E. The top of the uppermost black fissile or siliceous shale marks the top of the Round Prairie formation. In some parts of the mountains another siliceous shale is locally at the base of the lower bouldery shale.

Both of the bouldery shales contain exotic boulders which are ir-

[9] Hugh D. Miser, "Carboniferous Rocks of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), p. 984.

[10] Bruce H. Harlton, *op. cit.*, pp. 1037–42.

regularly intermixed in the shale and do not follow any definite bedding planes. They are mostly of Lower Paleozoic (Ordovician) limestones, but concretions, phosphatic nodules, and large specimens of *Orthoceras* from the Caney (Chester) occur commonly. The well worn pebbles, most of which vary in size from 0.25 inch to 3 inches in diameter, are entombed in a soft gray shale and are oriented with their longer axes parallel with bedding planes. Since the shale curves around the pebbles it appears that they are unquestionably depositional and were dropped into the mud during Round Prairie time. Boulders as large as 6 feet in diameter occur at many points. The soft gray bouldery shales almost everywhere weather to yellowish gray.

The presence in this marine shale of exotic pebbles and boulders representing formations from the Ordovician (Simpson) to the Bendian (Pushmataha) has been the subject of speculation since their discovery and various theories have been used to explain the incorporation of large boulders in a sedimentary mud. However, the definite placing of the Stapp conglomerate as a member of the Union Valley formation, and therefore older than Round Prairie, offers a simple solution.

This thick and widespread conglomerate of loosely bonded and poorly sorted material was deeply weathered and eroded by the advancing Round Prairie sea, and redeposited in the mud as individual pebbles or as unreduced conglomeratic boulders. The interstitial material, consisting of sand, gravel, and limestone fragments held together by a calcareous cement, was easily subject to weathering, and only slight current movements were necessary to bring the component material to its present position in the Round Prairie shale.

A striking exposure of the Round Prairie bouldery shale may be observed in Sec. 25, T. 3 S., R. 25 E., just south of the village of Stapp, Oklahoma, on U. S. Highway 270 (Fig. 19). These exposures are comparable to the complicated folded and faulted beds of the excellent exposures at Compton Railway cut.

Additional interesting evidence concerning the history of the exotics may be observed at this exposure. Some of the boulder arrangements (Fig. 18, Nos. 30–38) introduce a fascinating elucidation in this regard. At these stations a thick boulder zone is found, which is characterized by small pebbles approximately 0.25 inch in diameter, varying to cobbles and boulders some of them several feet in diameter. Many of the boulders are well rounded to subrounded and show interesting pitted surface phenomena, which undoubtedly occurred before they dropped into the matrix composing this zone. Most of the pebbles and cobbles also are rounded to subrounded and well worn, and

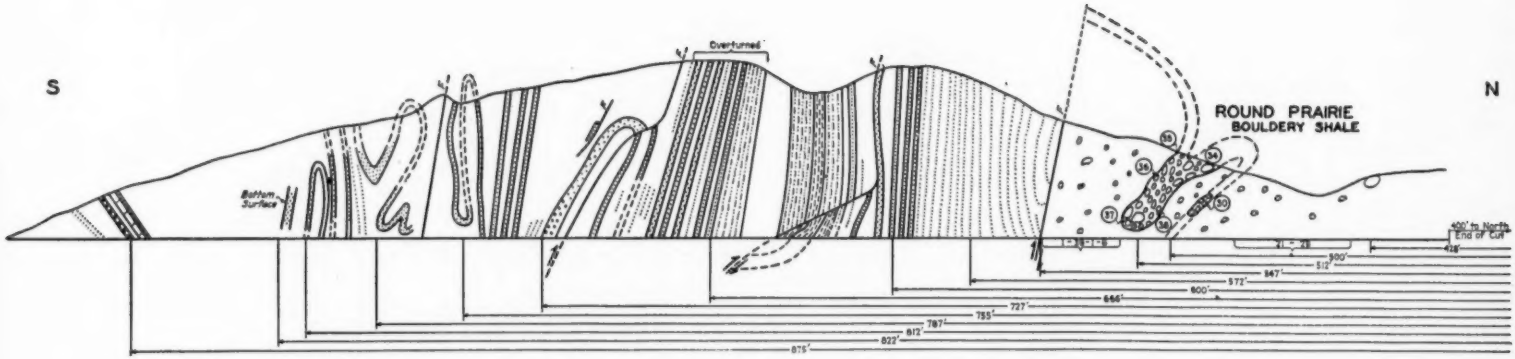


FIG. 19.—Diagram of beds exposed in road cut south of Stapp, showing position of boulders in Round Prairie shale referred to in text.

scores of them show the pitted surfaces. All exotics in this zone are very closely bonded in a terrigenous clayey deposit.

The bonding material of the boulder zone at this locality consists of red, greenish gray, yellowish gray, and slightly carbonaceous dark gray to black clay and shale. The colors are not distributed evenly and there is no suggestion of bedding planes. Splotches of clay of one color may lie adjacent to clay or shale of any other of the aforementioned colors. Everywhere within the matrix may be found sandstone or limestone grains, ranging from $\frac{1}{8}$ millimeter to several millimeters. These do not show any tendency toward being sorted, either by size or by type of material. Some surfaces show flat flakes of hematite, now partly weathered to limonite. The orientation of these hematite flakes suggests that they have been formed along planes of differential movements. The entire bonding composition shows no indication of normal bedding or sorting, commonly found in sediments deposited by water.

The boulders, cobbles, and pebbles within this zone are made up predominantly of limestone concretions and phosphatic nodules of Caney (Chester) age and different varieties of Simpson (Ordovician) sediments. Many cobbles and pebbles of black chert of Pushmataha (Bendian) age are found.

Several boulders and cobbles of conglomerate also are present in this zone, and some of the conglomeratic boulders are made up of the following constituents.

Drab arenaceous dolomite, matrix dense silty dolomite; tan dense limestone; greenish flaky shale in thin laminae; brown arenaceous dolomite. The bond is firm, limonitic.
Tan dense limestone; coarse rounded, frosted sand; dark gray shale; whitish gray bird's-eye-like limestone; brownish finely crystalline dolomite; brown arenaceous dolomite

Buff dense limestone; brown highly dolomitic, rounded frosted sand; brown arenaceous dolomite; gray finely crystalline arenaceous dolomite, sand grains rounded, frosted, and pitted—gilsonitic in part, much calcite veining; dark gray limestone concretions from the Caney of Chester age; black shale; clay ironstone concretions

Some cobbles of conglomerate are described as follows.

Tan dense limestone; buff finely crystalline limestone; brown arenaceous dolomite; light gray coarsely crystalline dolomite, siliceous residue consists of silicified brachiopod fragments probably of Trenton age

Rounded pebbles of gray coarsely crystalline fossiliferous limestone; dark gray Mississippian limestone concretions and brown arenaceous dolomite

Tan dense limestone matrix; grey arenaceous saccharoidal dolomite, grains rounded and frosted; black shale

Fauna.—The fauna of the Round Prairie formation has been described in part by the writer[11] under the old name Johns Valley shale.

[11] Bruce H. Harlton, "Micropaleontology of the Pennsylvanian Johns Valley of the Ouachita Mountains, Oklahoma, and Its Relationship to the Mississippian Caney Shale," *Jour. Pal.*, Vol. 7 (1933), pp. 1–29.

The foraminifera and ostracoda are the most plentiful fossils in the bouldery shale. The fissile, in places siliceous shale, which occurs at the top of the formation, contains a profusion of conodonts. The calcareous sandstones near the middle contain mostly brachiopods and gastropods. Many of the plentiful clay ironstone concretions characteristic of the shale have ammonoids encased (Fig. 20).

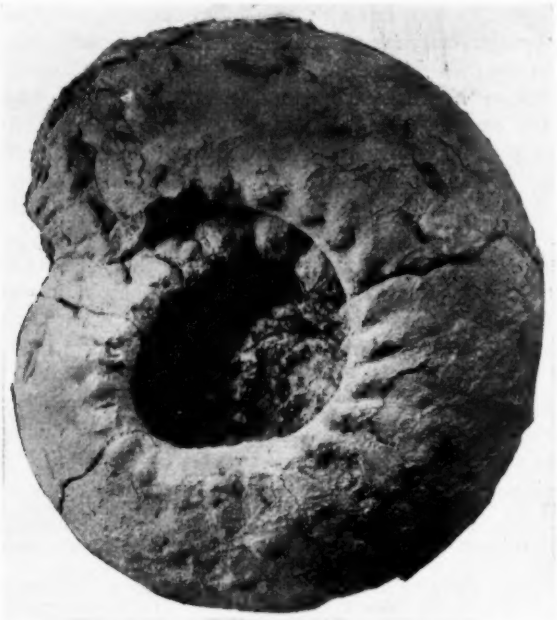


FIG. 20.—*Gastrioceras* n. sp. from Round Prairie formation, SE. ¼, NW. ¼, SW. ¼, Sec. 1, T. 2 S., R. 12 E. Natural size.

FRONTAL OUACHITAS

PRIMOSE FORMATION

Distribution.—The Primrose formation is exposed along the Choctaw fault zone. It is also well exposed in the strike-faulted northwestern frontal belts, unfortunately included by Taff in the Chickachoc chert lentils.

Thickness.—The Primrose formation was named by Tomlinson,[12]

[12] C. W. Tomlinson, "The Pennsylvanian System of the Ardmore Basin, Oklahoma," *Oklahoma Geol. Survey Bull. 46* (1929), p. 19.

in the Ardmore basin, where it reaches a maximum development. Its thickness varies greatly from place to place. Just southwest of Anderson Flat near the center of S. ½, Sec. 19, T. 3 S., R. 4 E., it measures 254 feet, and 5 miles east of the village of Springer, in a tributary of Cool Creek and along the railroad, its aggregate thickness is 642 feet. At the latter locality there may be some duplication by faulting. In the frontal belt of the Ouachitas, exposures have been found measuring about 20 feet in thickness. A good exposure may be observed on the main road south of Blanca near the center of the south line, NE. ¼, Sec. 25, T. 3 N., R. 14 E., where a thickness of about 12 feet was measured. In the Arbuckle Mountains it has been known as the "Union Valley limestone" and is only a few feet in thickness.

Lithologic character.—The Primrose consists in the main of drab and tan siliceous limestone, argillaceous, arenaceous siliceous limestone, gray platy siliceous shale, and black bituminous shale. Under the description of the Wapanucka, the measured section at Limestone Gap is described.

The most interesting feature of this formation wherever found is the great abundance of sponge spicules, which compose the matrix of most strata. Of great significance is the fact that the spicules of sponges actually constitute a rock-forming agency for most portions of this series. However, the fact should be borne in mind that many of the black carbonaceous shales, highly charged with spicules, show little or no secondary silica which might have acted as a chalcedonic bond in the further silicification of the rock. The probable reason for this further lack of silicification is that very finely divided clay particles prevented the injection of silica-charged water.

General weathering character.—Superficially the Primrose siliceous limestone appears to have characteristics resembling the massive siliceous cherty limestone occurring in the Wapanucka as well as in the upper part of the Barnett Hill formation. However, the Primrose cherts are very hard and ring when struck with a hammer.

Fauna.—The foraminifera, ostracoda, and conodonts are very prolific in the Primrose. The megascopic faunal assemblage is similar to that of the Union Valley.

LIMESTONE GAP SHALE

Distribution.—In the frontal Ouachitas, as well as in the Ardmore basin and the Arbuckle Mountains, one encounters above the Primrose and below the Wapanucka and the Jolliff limestone, respectively, a dark gray to black shale. In the Ouachitas it is well exposed along the Choctaw fault zone, but immediately south it crops out only in

fault zones in scattered exposures. The areal distribution of this shale in the Arbuckle Mountains is exceedingly spotty and unfortunately not traceable. However, in the Ardmore basin it is well developed. As this shale body is a distinct diastrophic, stratigraphic and lithologic unit, the term Limestone Gap is here proposed. The type locality was chosen at Limestone Gap, Sec. 31, T. 2 N., R. 13 E.

Thickness.—The thickness of this shale varies greatly from place to place as a result of overlap, which can be demonstrated in the subsurface at scores of places. The Seminole area, for example, offers a notable example of this. At the type locality this shale measures 44 feet from the top of the Primrose to the base of the Wapanucka limestone. In the Ardmore basin, about 5 miles east of the village of Springer, in a tributary of Cool Creek, along the railroad track near the center of SE. ¼, Sec. 1, T. 3 S., R. 2 E., it measures 1,250 feet.

Lithologic character.—The Limestone Gap shale consists of gray-greenish, dark gray, and black bituminous shale, containing a profusion of siderite layers and concretions. In the Ardmore basin the upper part ordinarily is predominantly silty and finely arenaceous, and the lower part only contains here and there thin arenaceous streaks. Scattered drab argillaceous limestone concretions with many fine plant fragments have been found at the latter locality. These concretions indeed resemble those occuring in the Caney shale, of the Chester series. The measured section of the type locality at Limestone Gap is described under the Wapanucka formation.

Fauna.—This shale is undoubtedly marked by extremely plentiful and highly characteristic fossils which occur regardless of its thickness. In thin layers one finds a profusion of conodonts, foraminifera, and ostracods. In the Wapanucka graben there are numerous faunal streaks in this shale and the most common type are the phosphatic inarticulate linguloid shells, commonly associated with *Orthoceras*. Also, many thin shells of depauperate pelecypods are found among the remains. These faunal types are commonly associated with a profusion of conodonts.

WAPANUCKA FORMATION

The Wapanucka formation has been defined in various ways by different writers. The differences of opinion respecting the ages arose largely from the fact that the original nomenclature by Taff[13] did not describe or designate a type locality. Hence it has been customary to accept the exposures at the town of Wapanucka as the type. Unfortunately, however, the section at this locality is not complete and

[13] J. A. Taff, "Coalgate," *U. S. Geol. Survey Atlas Folio 74* (1901).

units above the Wapanucka have been included at other exposures. The original description by Taff appears to have included chiefly or entirely the lower limestone series, and the same limits are observed in this paper.

In the extreme northwestern Ouachitas, this formation, together with the Barnett Hill formation, as well as the Primrose, was erroneously designated by Taff[14] as the Chickachoc chert lentils. Due to the great amount of strike faulting along this belt of the mountains, no complete continuous section has been found; consequently, at the localities observed, the entire upper Bendian sequence seemed to Taff an indivisible mass which was called Chickachoc. Later detailed surface studies have straightened out the stratigraphic sequence so that the proper position of the series of beds, now designated as Primrose, Wapanucka, and Barnett Hill, has been established. Because of the confused composition of the Chickachoc chert lentils, as described by Taff, it seems advisable to discard Chickachoc as a formational name in order to avoid confusion.

Distribution.—The excellent exposures one mile west of the village of Wapanucka include the Primrose formation, the Limestone Gap shale, and the massive Wapanucka limestone. At Barnett Hill, one mile north of the village of Clarita, in T. 1 S., R. 8 E., only the upper part of the Wapanucka limestone and the Barnett Hill are exposed. All of these formations are incongruously jumbled in the frontal part of the Ouachita Mountains.

The massive limestone part of the Wapanucka formation makes low ridges wherever exposed. From Chokie to Limestone Gap, Ts. 1 and 2 N., Rs. 12 and 13 E., it consists of alternating limestone and shales with the latter predominating. Eastward, just south of Blanco, the exposures located near the center of the east line, Sec. 24, T. 3 N., R. 14 E., show a very thick development of the limestones in the upper part, but farther east, near the vicinity of Arch and Hartshorne, the shales again predominate. The great lateral variations in thicknesses indicate differential oscillations during deposition.

The Wapanucka limestone affords one of many striking illustrations of the instability of the floor of the continent with respect to sea-level as a result of oft-repeated differential movements. The occurrence of many units seems patchy, indicating deposition in small depressions on a much warped floor. The lime-depositing Wapanucka phase is generally thought to be a synchronous deposit laterally changing into sandstone. However, these lithically changing stratigraphic zones were found to comprise deposits that were not only laid

[14] *Idem*, "Atoka," *U. S. Geol. Survey Atlas Folio 79* (1902)

down in physically distinct troughs, but their respective beds are not contemporaneous. The evidence of these disconnected, oscillating continental seas can be demonstrated by overlap.

Thickness.—The thickness of Taff's possible type locality one mile west of the village of Wapanucka at the water dam measures, to the fault, about 220 feet. At Limestone Gap, near the center of E. ½, Sec. 31, T. 2 N., R. 13 E., a section of 198 feet was measured. South of the Choctaw fault a great variation may be observed.

Lithologic character.—This formation consists of alternating limestones and shales, and here and there sandy limestones.

The best section of the Wapanucka limestone in the Ouachitas with the underlying Limestone Gap and Primrose formations may be observed at Limestone Gap.

SECTION AT LIMESTONE GAP

Primrose Formation

Feet	
0– 1	Massive, light gray, argillaceous, siliceous, sponge spicular limestone
4	Drab greenish, slightly arenaceous, nodular shale, made up almost entirely of sponge spicules
9	Tan, siliceous, massive, sponge spicular limestone, argillaceous in part—composed almost entirely of spicules

Limestone Gap Shale

0– 44	Dark gray to black shale with great profusion of siderite nodules and concretions

Wapanucka Limestone

0– 1½	Light gray, finely crystalline, highly fossiliferous limestone with large rounded oölites (residue leaves siliceous network of fine shell fragments, sponge spicules and glauconite) and intercalated thin seams of highly argillaceous and glauconitic limestone containing a profusion of sponge spicules and crinoids
2½	Black, well laminated, siliceous shale made up almost entirely of sponge spicules
10½	Black, fossiliferous, flaky shale and very thin seams of argillaceous fossiliferous siltstone with many sponge spicules. *Spirillina* and *Hyperammina*
13	Gray, argillaceous, siliceous limestone, composed of sponge spicules. This limestone in part is highly argillaceous, in portions containing *Goniotites*
63	Dark gray splintery shale with many bright red ironstone concretions which vary in size from ½ inch to 20 inches, and many siderite layers
66	Dark gray, black, fissile shale composed almost entirely of spicules. Many *Healdia*, few *Goniotites* remains
68½	Grading upward to massive, argillaceous, siliceous, sponge spicular limestone. *Algo* sprays
72½	Dark gray, fissile, chonchoidal shale with profusion of sponge spicules. Many *Bellerophon* remains
76⅞	Dark gray, argillaceous, sponge spicular, siliceous limestone, basal one foot, highly argillaceous
77	Dark gray to black, calcareous, fossiliferous shale with very thin laminae of argillaceous, arenaceous, glauconitic, crinoidal limestone, some patches composed entirely of sponge spicules. The shale contains a profusion of crinoid remains, also *Bellerophon*, *Pleurotomaria*, *Kirkbya*, *Amphissites*, *Healdia*, *Paraparchites*, *et cetera*
82	Basal portion consists of light gray, very massive, argillaceous, arenaceous, glauconitic, finely crystalline, highly fossiliferous limestone, containing many sponge spicules, grading upward to dense to crypto-crystalline argillaceous limestone, also containing many sponge spicules
85⅝	Dark gray to black, calcareous, fossiliferous shale, with few included sand grains and many blebs of glauconite, containing many conodonts and a profusion of sponge spicules

Feet	
93	Basal 1 foot consists of gray, crypto-crystalline, argillaceous, slightly arenaceous, fossiliferous limestone, grading to very massive, dense limestone with splotches of chalcedony. Very thin laminae of shale between bedding planes. Top 3 feet varies to gray, finely crystalline, arenaceous, somewhat siliceous limestone. This entire limestone body contains a profusion of sponge spicules
96½	Dark gray, highly argillaceous, marly, siliceous limestone with profusion of sponge spicules
98½	Dark gray, calcareous, fossiliferous shale, with many included sponge spicules
107	Gray, highly argillaceous, siliceous limestone, almost entirely made up of sponge spicules
112	Black, calcareous, fossiliferous shale
128	Massive and thin-bedded, highly argillaceous, silty to finely arenaceous, slightly glauconitic, siliceous limestone, containing a great profusion of sponge spicules
137½	Black, calcareous, fossiliferous shale, containing many different species of *Kirkbya*, some *Hippocrepina bendensis*. This shale contains many thin seams of argillaceous, glauconitic, siliceous limestone, composed of fossil fragments and sponge spicules in the main. Fossil fragments consist almost entirely of ostracods
141½	Gray, argillaceous, silty to finely arenaceous, glauconitic, siliceous limestone
143½	Light gray, brownish, coarse crystalline, highly glauconitic, crinoidal, arenaceous limestone, highly oölitic in part, basal portion highly argillaceous, somewhat siliceous
149½	Gray, highly argillaceous, glauconitic, siliceous limestone almost entirely made up of sponge spicules and intercalated thin, calcareous, marly shale
151½	Dark gray, black, calcareous, marly shale
159½	Gray, thin to massive, argillaceous, siliceous limestone, composed almost entirely of spicules
182½	Light brownish, weathered, highly fossiliferous shale. *Gastrioceras*, *Hustedia*, *Kirkbya*, *Amphissites*, *Healdia*
185½	Light gray, brown, finely crystalline arenaceous, argillaceous, glauconitic, highly fossiliferous limestone. Profusion of *Bellerophon*
196½	Dark gray shale
198	Light brown to tan marly fossiliferous highly limonitic limestone containing many sponge spicules
	Barnett Hill Formation
0–130	Dark gray to black shale, weathers gray to olive, containing a profusion of siderite nodules and concretions
140	Thin-bedded, highly argillaceous, finely arenaceous, cross-bedded limestone, containing a profusion of sponge spicules. Top portion becomes highly fossiliferous and included sand grains are coarser
141½	Light gray, very coarse crystalline, fossiliferous limestone; basal 2 feet closely intermixed gray, argillaceous, siliceous limestone and buff, coarsely crystalline, arenaceous limestone
145½	Black, thinly laminated, siliceous shale, almost completely made up of sponge spicules
146¾	Whitish gray, coarsely crystalline, arenaceous, fossiliferous limestone
175¾	Massive and thin-bedded, gray, argillaceous, cherty limestone with profusion of sponge spicules; chert occurs in bands, in some layers it occurs in patches, which are not completely developed in chalcedony. On hill side, the chert is highly leached
177¾	Massive, light brown, highly oölitic limestone
182¾	Whitish gray, dense to very finely crystalline, sponge spicular limestone, with minute seams and pockets of chalcedonic material
185¾	Grading upward into mostly blue chert
191¾	Very massive (one bed), coarsely crystalline, highly crinoidal, glauconitic limestone with some closely intermixed finely arenaceous limestone. Many sponge spicules
215	Basal 1 foot, chert, containing profusion of sponge spicules, grading upward into gray to light gray, brownish, argillaceous, fossiliferous limestone with closely intermixed chert
243	Whitish gray, buff and white, dense to finely crystalline limestone, weathers smoothly cavernous
247	Black, arenaceous, sponge spicular chert

Another good exposure of the Wapanucka and the overlying Barnett Hill formation is at the Hartshorne limestone quarry, south of the town of Hartshorne (Fig. 20).

SECTION OF HARTSHORNE QUARRY STA. 48

Wapanucka Limestone

Measured along west bank of creek just west of quarry

Feet	
0–	Fault
0– 9	A. Light gray to gray, argillaceous, cherty limestone
10½	B. Light gray, coarsely crystalline, glauconitic, fossiliferous limestone
85	C. Dark gray shale
91	D. Light gray to gray, finely crystalline, argillaceous, fossiliferous, cherty limestone, containing many sponge spicules
142	E. Dark gray shale
148½	F. Light gray brownish, finely crystalline, fossiliferous limestone with profusion of sponge spicules
	G. Upper part varies to coarsely crystalline, glauconitic, fossiliferous limestone
182½	H. Dark gray shale
200	I. Gray, crypto-crystalline, cherty limestone, almost entirely composed of spicules
	Beds A, D, F, and I weather to a tan yellowish, siliceous mass, leaving for the most part a network of spicules

Barnett Hill formation

Measurements continued along west bank of creek

0– 75	1. Dark gray to black, fossiliferous shale
78½	2. Whitish gray to brownish, coarsely crystalline, fossiliferous limestone
89	3. Gray, dense to crypto-crystalline limestone, weathers to a very finely siliceous mass, containing a profusion of sponge spicules
	4. Grading to tan, buff, finely crystalline, argillaceous, crinoidal limestone. Also contains many sponge spicules. The crinoids vary in size from 1 millimeter to 16 millimeters. This limestone is highly leached when weathered, leaving for the most part a network of crinoidal remains
95½	5. Dark gray shale
124	6. Base. Light brown, crystalline, crinoidal, highly oölitic limestone
	7. Becomes less crinoidal. The coarse oölites practically compose the matrix of this entire zone
	8. Dark gray shale. 15½ feet thick

Measurements continued on east end of quarry

	7. This bed is the same as bed 7 on west bank of creek. Light brown, highly oölitic, fossiliferous limestone. Crinoids, *Bransonella*. This limestone measures only 4½ feet at this locality
143	8. Dark gray, flaky shale. This bed is the same as bed 8 on west bank of creek
149½	9. Very massive, light gray, brownish, arenaceous, highly fossiliferous limestone, with some disseminated glauconite. Crinoids, *Climacammina*, *Rhombopora*, *Lioclema*
154½	10. Massive, light gray, dense, argillaceous limestone. Upper 1 foot consists of closely intermixed dark gray shale and limestone
156½	11. Dark gray, highly fossiliferous shale, alternating with thin fossiliferous limestone nodules, composed of a multitude of sponge spicules. Many *Amphissiles*
157½	12. Thin-bedded, nodular, highly argillaceous, fossiliferous limestone, with thin laminae of dark gray shale. Limestone contains profusion of crinoidal remains
164½	13. Very massive, dense to crypto-crystalline limestone, weathers to irregular cherty masses. Many small to very large crinoids

Feet	
178½	14. Very massive, gray, dense, highly crinoidal limestone. Many corals
180	15. Light brown, highly oölitic, fossiliferous limestone. Many crinoids and conodonts
185½	16. Grading to massive, light gray and gray dense to crypto-crystalline limestone, containing thin bands and occasional splotches of chert. Limestone slightly argillaceous in part.
	16a. Upper 10 inches highly argillaceous and platy
187	17. Whitish gray, buff, dense limestone. *Productus*
	18. Upper 4 inches dark gray fossiliferous shale
188½	19. Massive, gray, argillaceous, crypto-crystalline limestone
196½	20. Dark gray, calcareous, fossiliferous shale
213½	21. Thin-bedded, gray, crypto-crystalline, argillaceous, fossiliferous limestone alternating with thin laminae of dark gray shale
	22. Argillite content increases, limestone and shale become closely intermixed. Large coarse crinoid stems ranging to 6 inches are imbedded in these sediments
220	23. Gray greenish, highly argillaceous, thin-bedded limestone. The bedding planes are well exposed in this quarry. Due to weathering they exhibit a remarkably raised very small nodular surface effect. The nodules, up to 20 millimeters in diameter, are rounded to subrounded in shape. Profusion of crinoids and trilobites
	23a. On top of hill (cliff former) becomes highly silicified and leached and weathers to yellowish green. The nodules are raised as in 23
238	24. Very massive, buff, minutely to coarsely oölitic, fossiliferous limestone. Basal 5 feet cherty. Many crinoids
243	25. Same as above, but upper part becomes pinkish and very coarsely crystalline
264½	26. Massive, gray, dense to crypto-crystalline limestone, weathers to large irregular nodular masses
269	27. White and pink, finely crystalline limestone. Top 2 inches weathers cherty
272	28. Varies to very highly glauconitic fossiliferous limestone with thin laminae of bright green shale. Near top, becomes finely arenaceous
279	29. Brown, coarsely crystalline, highly fossiliferous limestone, weathers to tan yellowish color. Basal part slightly glauconitic
291½	30. White crypto-crystalline limestone, with many irregular splotches of green argillite
319½	31. Very massive, white to whitish gray, dense to cryptocrystalline fossiliferous limestone
325½	32. Basal 1 foot, gray, brown, limonitic, arenaceous, fossiliferous limestone (much $CaCO_3$ dissolved out), containing many splotches, and tiny laminae of gray greenish and light green argillite; sand grains predominantly medium to coarse, rounded to subrounded. Succeeding 3 feet, green, argillaceous, highly arenaceous, hematitic fossiliferous limestone. Due to great amount of hematite it weathers to bright red and deep maroon-red. Crinoidal remains profuse and in some cases compose the matrix. Top 1½ feet, same as basal 1 foot, except much hematite. Profusion of crinoids. *Dialasma, Girtyella, Spirifer*
328½	33. Massive, gray, argillaceous, arenaceous, fossiliferous limestone, some included glauconite, many crinoids, *Spiriferina*, bryozoans
337½	34. Massive, gray, argillaceous limestone and thin laminae of dark gray shale. Many sponge spicules and corals
355½	35. Buff, yellowish, highly leached chert, and white and red mottled highly arenaceous, argillaceous, fossiliferous cherty limestone, lime dissolved completely. Sandstone grains are fine, subangular; red argillite predominates This chert alternates with red, argillaceous, very fine, calcareous sandstone, with quartzitic tendency. Replaced silica in patches. Large tapering spines. Crinoids to 16 millimeters in diameter

Near Middle of Quarry (Fig. 20)

6	50. Black bituminous shale
16	51. Same as 33 and 34
18	52. Same as 35

Feet	
46	53. Tan, fine to medium subrounded to subangular sandstone, with some included large flakes of muscovite grading upward to red, fine to medium-coarse subangular sandstone, also containing some large muscovite flakes
	54. Same as 35

Locally the Wapanucka limestone is thickly charged with floating rounded to subrounded quartz grains. This probably represents deposition in an embayment in the southern border of the sea, whose deeper part lay on the north and west. Additional evidence of overlapping conditions is furnished by many limestones and arenaceous limestones which are imperfectly stratified near the basal part and contain many inclusions of variegated shale in patches and seams. In many places the basal part of the arenaceous limestone is closely intermixed with an agglomeration of loose surface matter, showing that the initial deposit consisted mainly of wave-transported regolith and its principal service was to pave the way for succeeding regular deposition from the newly introduced submergence.

Fauna.—In the frontal Ouachitas and extending westward into the Wapanucka graben in T. 2 S., Rs. 8 and 9 E., one may find practically the entire section of the Wapanucka thickly charged with spicules of sponges. The area between Chokie, in T. 1 N., R. 12 E., and the town of Wilburton, in T. 5 N., R. 19 E., became an important center of sponge development and dispersal. The corals, brachiopods, foraminifera, and ostracods are especially prolific in the Wapanucka.

BARNETT HILL FORMATION

The Barnett Hill formation, originally included by Taff in the lower Atoka formation, contains an unquestionable Morrow fauna. Therefore, this part of the Atoka was separated from the overlying sediments of Des Moines age by the writer in 1934. As pointed out at that time[15] this Morrow unit changes laterally in very short distances. The dense limestone, excellently exposed immediately north of Goose Creek in Secs. 18 and 19, T. 1 N., R. 8 E., is absent at Barnett Hill, one mile north of Clarita. However, the sandstones which overlie this limestone are found in splendid development at the latter locality and contain a great profusion of cephalopods. The fusulinid bed which stratigraphically underlies the dense limestone is present at both places.

In the northwestern Ouachitas the upper half of the formation, which consists entirely of limestone and chert, is well developed. Many persistent zones occur in the section and can be traced, with fairly uniform lithologic character, over a large area, but the intervening zones vary from chert and cherty limestone in the northwest to

[15] Bruce H. Harlton, *op. cit.*, p. 1025.

intercalated sandstones on the east and southeast. On the generalized section (Fig. 23) the zones which extend uniformly over wide areas are designated Zones I, II, III, and IV.

Among the important facts brought out by these studies is the evidence that the lithologic contact of this formation with the underlying Wapanucka is distinct and characteristic in both the Ouachitas and the Arbuckles. It is marked by highly diagnostic foraminifers and ostracods, as well as by characteristic ammonoids and trilobites of typical Morrow age, thus supporting the evidence offered by the foraminifers and ostracods.

Distribution.—The Barnett Hill is excellently exposed south of the Choctaw fault at the Hartshorne quarry (Fig. 21) and continues eastward to the Arkansas state line. A good exposure is noted at the top of the Bendian section in Round Prairie.

Thickness.—Because of the overlapping character of this formation, it is to be expected that its thickness is erratic from place to place. The thickness observed in the Ouachitas varies from 200 to 500 feet.

Lithologic character.—This formation received its name from Barnett Hill, one mile north of Clarita, Sec. 2, T. 1 S., R. 8 E. A second type section[16] was chosen at Goose Creek in Secs. 19 and 20, T. 1 N., R. 8 E. The detailed description of this formation is shown in a graphic section (Fig. 22).

In the lower part of the Prairie Mountain exposures one may observe several thin, light gray, arenaceous, fossiliferous limestones, with many included small white chert fragments. The sandstones in the upper part also are highly fossiliferous, almost approaching limestone. The top is marked by a siliceous shale or chert, and is correlated with Zone IV in the frontal belt of the mountains.

General weathering character.—As previously pointed out, the cherts in the upper part of the Barnett Hill superficially resemble the Wapanucka and Primrose. Examination of many exposures in the Ouachitas show these cherts to be very different from the massive hard Wapanucka and Primrose. As a rule, the cherts are porous and mottled red; some layers are dense and brittle, and commonly scoriaceous. Most of the chert breaks easily under the hammer.

Fauna.—The calcareous sandstones are highly fossiliferous, both megascopic and microscopic. Many of the shells are only partly dissolved, and the details of structure and surface ornamentation are still preserved. Plant fragments also are common. The shales and

[16] This section was first shown to the writer by Horace L. Griley, who has devoted much time to study of the Atoka formation.

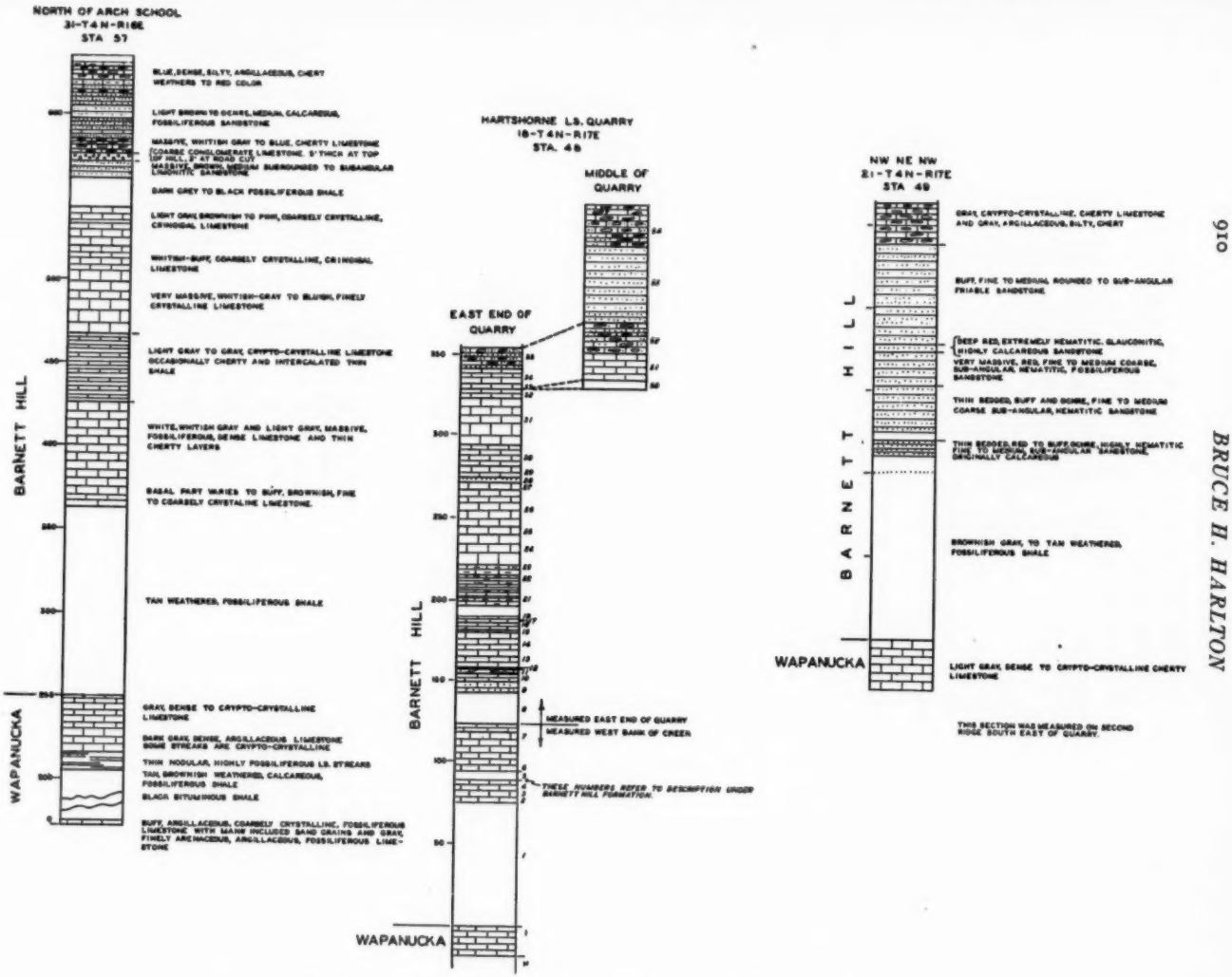

NORTH OF ARCH SCHOOL
31-T4N-R18E
STA 57
BARNETT HILL
WAPANUCKA
BLUE, DENSE, SILTY, ARGILLACEOUS, CHERTY
WEATHERS TO RED COLOR
LIGHT BROWN TO OCHRE, MEDIUM, CALCAREOUS, FOSSILIFEROUS SANDSTONE
MASSIVE, WHITISH GRAY TO BLUE, CHERTY LIMESTONE
(COARSE CONGLOMERATE LIMESTONE, 5' THICK AT TOP OF HILL, 5' AT ROAD CUT)
MASSIVE, BROWN, MEDIUM SURROUNDED TO SUBANGULAR LIMONITIC SANDSTONE
DARK GREY TO BLACK FOSSILIFEROUS SHALE
LIGHT GRAY, BROWNISH TO PINK, COARSELY CRYSTALLINE, CRINOIDAL LIMESTONE
WHITISH-BUFF, COARSELY CRYSTALLINE, CRINOIDAL LIMESTONE
VERY MASSIVE, WHITISH-GRAY TO BLUISH, FINELY CRYSTALLINE LIMESTONE
LIGHT GRAY TO GRAY, CRYPTO-CRYSTALLINE LIMESTONE OCCASIONALLY CHERTY AND INTERCALATED THIN SHALE
WHITE, WHITISH GRAY AND LIGHT GRAY, MASSIVE, FOSSILIFEROUS, DENSE LIMESTONE AND THIN CHERTY LAYERS
BASAL PART VARIES TO BUFF, BROWNISH, FINE TO COARSELY CRYSTALINE LIMESTONE.
TAN WEATHERED, FOSSILIFEROUS SHALE
GRAY, DENSE TO CRYPTO-CRYSTALLINE LIMESTONE
DARK GRAY, DENSE, ARGILLACEOUS LIMESTONE SOME STREAKS ARE CRYPTO-CRYSTALLINE
THIN NODULAR, HIGHLY FOSSILIFEROUS LS. STREAKS
TAN BROWNISH WEATHERED, CALCAREOUS, FOSSILIFEROUS SHALE
BLACK BITUMINOUS SHALE
BUFF, ARGILLACEOUS, COARSELY CRYSTALLINE, FOSSILIFEROUS LIMESTONE WITH MANY INCLUDED SAND GRAINS AND GRAY, FINELY ARENACEOUS, ARGILLACEOUS, FOSSILIFEROUS LIMESTONE
HARTSHORNE LS. QUARRY
18-T4N-R17E
STA. 48
MIDDLE OF QUARRY
EAST END OF QUARRY
BARNETT HILL
WAPANUCKA
MEASURED EAST END OF QUARRY
MEASURED WEST BANK OF CREEK
THESE NUMBERS REFER TO DESCRIPTION UNDER BARNETT HILL FORMATION.
NW NE NW
21-T4N-R17E
STA 49
BARNETT HILL
WAPANUCKA
GRAY, CRYPTO-CRYSTALLINE, CHERTY LIMESTONE AND GRAY, ARGILLACEOUS, SILTY, CHERT
BUFF, FINE TO MEDIUM, ROUNDED TO SUB-ANGULAR FRIABLE SANDSTONE
DEEP RED, EXTREMELY HEMATITIC, GLAUCONITIC, HIGHLY CALCAREOUS SANDSTONE
VERY MASSIVE, RED, FINE TO MEDIUM COARSE, SUB-ANGULAR, HEMATITIC, FOSSILIFEROUS SANDSTONE
THIN BEDDED, BUFF AND OCHRE, FINE TO MEDIUM COARSE SUB-ANGULAR, HEMATITIC SANDSTONE
THIN BEDDED RED TO BUFF OCHRE, HIGHLY HEMATITIC FINE TO MEDIUM, SUB-ANGULAR SANDSTONE, ORIGINALLY CALCAREOUS
BROWNISH GRAY, TO TAN WEATHERED, FOSSILIFEROUS SHALE
LIGHT GRAY, DENSE TO CRYPTO-CRYSTALLINE CHERTY LIMESTONE
THIS SECTION WAS MEASURED ON SECOND RIDGE SOUTH EAST OF QUARRY.

FIG. 21.—Detailed description of Barnett Hill formation at Hartshorne vicinity.

FIG. 21.—Detailed description of Barnett Hill formation at Hartshorne vicinity.

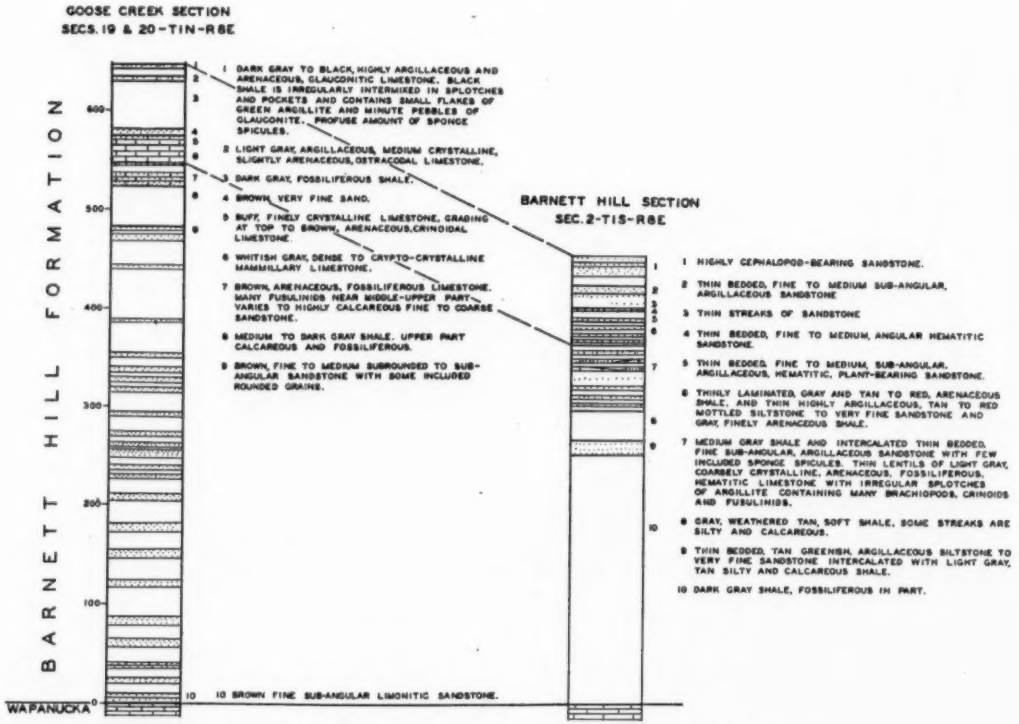

GOOSE CREEK SECTION
SECS. 19 & 20-T1N-R8E
BARNETT HILL FORMATION
600
500
400
300
200
100
0
WAPANUCKA
1 DARK GRAY TO BLACK, HIGHLY ARGILLACEOUS AND ARENACEOUS, GLAUCONITIC LIMESTONE. BLACK SHALE IS IRREGULARLY INTERMIXED IN SPLOTCHES AND POCKETS AND CONTAINS SMALL FLAKES OF GREEN ARGILLITE AND MINUTE PEBBLES OF GLAUCONITE. PROFUSE AMOUNT OF SPONGE SPICULES.
2 LIGHT GRAY, ARGILLACEOUS, MEDIUM CRYSTALLINE, SLIGHTLY ARENACEOUS, OSTRACODAL LIMESTONE.
3 DARK GRAY, FOSSILIFEROUS SHALE.
4 BROWN, VERY FINE SAND.
5 BUFF, FINELY CRYSTALLINE LIMESTONE, GRADING AT TOP TO BROWN, ARENACEOUS, CRINOIDAL LIMESTONE.
6 WHITISH GRAY, DENSE TO CRYPTO-CRYSTALLINE MAMMILLARY LIMESTONE.
7 BROWN, ARENACEOUS, FOSSILIFEROUS LIMESTONE. MANY FUSULINIDS NEAR MIDDLE-UPPER PART. VARIES TO HIGHLY CALCAREOUS FINE TO COARSE SANDSTONE.
8 MEDIUM TO DARK GRAY SHALE. UPPER PART CALCAREOUS AND FOSSILIFEROUS.
9 BROWN, FINE TO MEDIUM SUBROUNDED TO SUB-ANGULAR SANDSTONE WITH SOME INCLUDED ROUNDED GRAINS.
10 BROWN FINE SUB-ANGULAR LIMONITIC SANDSTONE.
BARNETT HILL SECTION
SEC. 2-T1S-R8E
1 HIGHLY CEPHALOPOD-BEARING SANDSTONE.
2 THIN BEDDED, FINE TO MEDIUM SUB-ANGULAR, ARGILLACEOUS SANDSTONE
3 THIN STREAKS OF SANDSTONE
4 THIN BEDDED, FINE TO MEDIUM, ANGULAR HEMATITIC SANDSTONE.
5 THIN BEDDED, FINE TO MEDIUM, SUB-ANGULAR, ARGILLACEOUS, HEMATITIC, PLANT-BEARING SANDSTONE.
6 THINLY LAMINATED, GRAY AND TAN TO RED, ARENACEOUS SHALE, AND THIN HIGHLY ARGILLACEOUS, TAN TO RED MOTTLED SILTSTONE TO VERY FINE SANDSTONE AND GRAY, FINELY ARENACEOUS SHALE.
7 MEDIUM GRAY SHALE AND INTERCALATED THIN BEDDED, FINE SUB-ANGULAR, ARGILLACEOUS SANDSTONE WITH FEW INCLUDED SPONGE SPICULES. THIN LENTILS OF LIGHT GRAY, COARSELY CRYSTALLINE, ARENACEOUS, FOSSILIFEROUS, HEMATITIC LIMESTONE WITH IRREGULAR SPLOTCHES OF ARGILLITE CONTAINING MANY BRACHIOPODS, CRINOIDS AND FUSULINIDS.
8 GRAY, WEATHERED TAN, SOFT SHALE, SOME STREAKS ARE SILTY AND CALCAREOUS.
9 THIN BEDDED, TAN GREENISH, ARGILLACEOUS SILTSTONE TO VERY FINE SANDSTONE INTERCALATED WITH LIGHT GRAY, TAN SILTY AND CALCAREOUS SHALE.
10 DARK GRAY SHALE, FOSSILIFEROUS IN PART.

FIG. 22.—Detailed description of Barnett Hill formation of type locality.

limestones contain faunal types similar to those in the underlying Wapanucka. Some of the calcareous sandstone layers contain a profusion of sponge spicules.

Correlation.—In the Ardmore basin the Barnett Hill formation is correlated with sediments from the top of the Lester to the top of the Otterville limestone. The Dornick Hills formation of Tomlinson

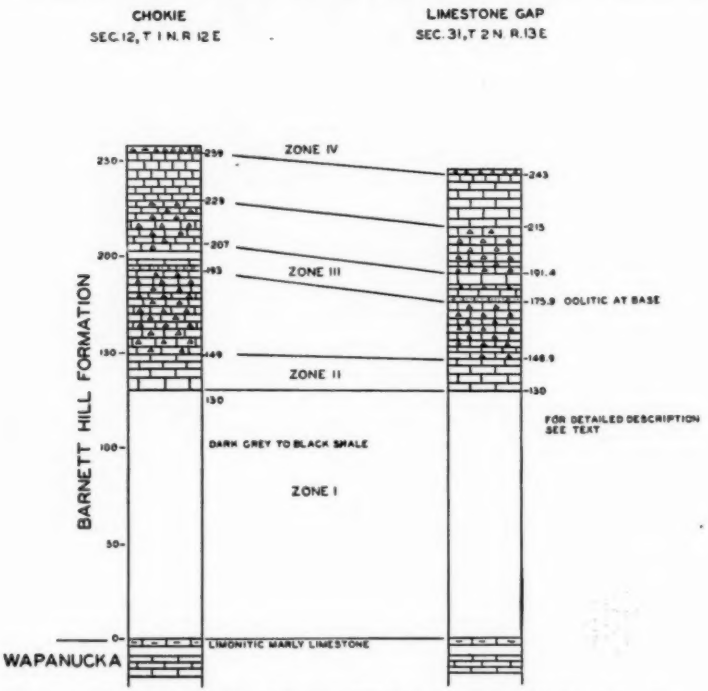


FIG. 23.—Generalized section of Barnett Hill formation at Chokie-Limestone Gap area, Ts. 1 and 2 N., Rs. 12 and 13 E.

comprises sediments both of Morrow and Des Moines age. Therefore, its name should be restricted to the Morrow part only. In Texas, the Barnett Hill formation is correlated with the Marble Falls and the Smithwick.

SILICEOUS SHALES AS CRITERIA FOR SUBDIVISION OF THE BENDIAN

As has been shown, siliceous shale deposits are the predominant factors that determine the location of the new formational units into which the Stanley and Jackfork have been subdivided. These shales

are very persistent and are continuous through the entire area, but the massive sandstones and intervening shales vary greatly. This irrefutably indicates quiescence during the siliceous shale deposition and active oscillatory movements during the sandstone deposition. Another feature which stands out prominently is that the Pushmataha sandstones and intervening shales thin conspicuously in the western limits of the Ouachitas. Most of the siliceous shales show individual characteristics, although some of them are similar and difficult of differentiation and one is forced to depend wholly or chiefly on faunal criteria. This applies in particular to beds exposed in the many strike-faulted belts. The physical characteristics of the associated beds aid immeasurably in the determination of the various siliceous beds. Hendricks,[17] Knechtel, and the writer have tested and applied the latter criteria successfully in many parts of the Ouachita Mountains.

The distribution and characterization of the Bendian siliceous shales in the Ouachitas are of far-reaching importance in surface studies. All of them make definite lithologic formational subdivisions but since most of the lithic characters are similar it seems obvious that rhythmically recurring cycles operated alike in all cases. The real cause of these cycles probably remains to be discovered. However, a few selected facts favor the interpretation that the presence of fauna consisting almost wholly of radiolaria, annelids, sponges, and spores suggests that the water in which they were deposited lacked calcium carbonate. Silica, which exists in water almost wholly as a colloid, is most readily precipitated by electrolites, such as calcium and magnesium carbonates, and since the type of life present suggests an absence of these elements, it may be supposed that the waters were highly charged with silica. These four organisms are known to utilize silica readily in forming their hard parts, and to be adaptable to such conditions as postulated. The evidence, therefore, points toward stagnant waters, low in alkaline carbonates and low in carbon dioxide, —an environment, therefore, unfavorable for accumulation of organic mud, but highly favorable for the diagenetic deposition of siliceous shale.

The Chickasaw Creek and the Wesley siliceous shales are the most widespread and best displayed formations. Here and there in both are intercalations of thin seams of non-calcareous black shales containing brachiopoda and other marine organisms of strictly cosmopolitan habitat. As a rule, the non-calcareous black shales of the Chickasaw Creek are crowded with radiolaria. These organisms, of course, require currents to effect their distribution and marine thoroughfares

[17] Thomas A. Hendricks. Personal communication.

were probably present at intervals during the deposition of the siliceous shales, retrieving the stagnant conditions and reducing the silica content of the waters. Depending on such evidence, one may entertain the interpretation that brief interruptions of the stagnant condition allowed the deposition of occasional black shales.

All of the siliceous shales were deposited at comparatively shallow depth, as demonstrated by the occurrence of many thin lenses of intraformational chert conglomerates. Most of the siliceous shales are highly fossiliferous in seams containing in the main a profusion of conodonts. Radiolaria and spicules of sponges are found to be most plentiful. Occasionally spores abounded in shallow off-shore lagoonal inlets. Vegetable fouling certainly prevailed as is shown by the high percentage of carbonized material in many of these shales. Macroscopically, no difference exists between the siliceous shale units without marine fossils and the matrix of the thin seams which are crowded with them, as well as those charged with carbonaceous material.

From the evidence of the microscopic examination of scores of thin sections, it seems unquestionable that the siliceous character of the shale was intimately connected with the occurrence of volcanic ash.

A full discussion of the paleogeographic and historic events would fill many pages and will be reserved for a later occasion.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 915-924, 3 FIGS.

GEOLOGICAL NOTES

POSSIBLE NATURE OF LIMESTONE RESERVOIRS IN THE PERMIAN BASIN[1]

H. P. BYBEE[2]
Austin, Texas

Petroleum in West Texas is found both in limestone and in numerous sands above the limestone. It is the writer's opinion that a considerable amount of this petroleum in limestone accumulated in voids formed by an erosional cycle when the limestone was near the surface.[3] The subsurface drainage near Bloomington, Indiana, as described by J. W. Beede,[4] suggests what probably happened in these limestone areas to make it possible for them to store such quantities of oil. Limestone which has not been subjected to such treatment would neither contain nor give up oil so freely as does the limestone of the West Texas reservoirs.

The porosity of the West Texas limestone reservoirs is without doubt much more open than could be expected to result from the change of limestone to dolomite. This idea is partly supported by the following data.

1. Cores of limestone indicate that the general texture is too tight to hold much oil where solution is not in evidence.

2. Shooting the limestone apparently aids by opening additional solution cavities. Acid treatment aids in the same manner.

3. Many large cavities or caves have been penetrated by the drill. Some of these have been so large as to require hundreds of tons of débris for filling. The considerable number of known limestone caves suggests that it would not be exceptional for them to occur in the limestone-producing areas of West Texas.

4. There is a marked variation in the sizes of limestone wells in any area. A striking example is The Texas Company's No. 11 on the Landreth strip in the Church and Fields pool, Crane County. This well has produced much more oil than the other 15 wells on the strip combined. The adjacent wells are reported to be unaffected by the operation of this well, showing that their reservoirs are apparently not connected. This does not indicate normal porosity.

[1] Read before the Association at New Orleans, March 17, 1938. Manuscript received, April 5, 1938.

[2] Department of Geology, University of Texas.

[3] W. V. Howard suggested this as early as 1930.

[4] J. W. Beede, "Subterranean Drainage in the Bloomington Quadrangle," *Indiana Acad. Sci.* (1910).

5. Four wells are grouped around the center of Section 13, Block 35, University lands, Crane County. One has an initial production of 486 barrels, another 380 barrels, and a fourth 11,480 barrels natural. The first three wells have been either shot or treated with acid, or both. This indicates a considerable variation in porosity and might suggest that the well had penetrated a cavity filled with oil, rather than a reservoir of average porosity.

6. There is a definite unconformity between the Ordovician and the Pennsylvanian in the Big Lake oil field, with production below the unconformity.[5]

7. Sand is present in and immediately above the limestone in many areas, indicating a marked variation in deposition and suggesting at least a disconformity.

8. A study of the cuttings from the Shell-Kirby's University No. 1, Sec. 23, Blk. 26, University lands, Pecos County, leads one to believe that there is a considerable unconformity at the top of the limestone section.

9. F. L. Whitney, of the Department of Geology of the University of Texas, has found a considerable unconformity at the top of the Edwards limestone north of Luling which may have caused the high porosity of that field.

The following illustration is pertinent. If the Carlsbad Caverns were buried to the depth of production in the Winkler field an ideal reservoir would exist for the accumulation of oil. It is this type of picture that the writer has for the accumulation of oil in many of the West Texas "lime" pools.

The Hendrick pool in Winkler County, to October 31, 1937, has produced 192 million barrels of oil. Convert this into space required for storage and a room 100 feet high, 200 feet wide, and 10.18 miles long is required. The daily production of 15,000 barrels would add a 4.2-foot addition to the room every day, or extend the room 1,500 feet per year.

After consultation with Thomas Boles, superintendent of the Carlsbad Caverns, it is estimated that a minimum of 560 million cubic feet of rock has been excavated by underground solution in the formation of the Carlsbad Caverns. Inasmuch as one barrel of oil contains 5.6 cubic feet of space, it is evident that the Caverns would hold little in excess of 100 million barrels of oil. This would leave a balance of 92 million barrels after the total production to date of the Hendrick pool had been stored in the Caverns. It seems probable that natural porosity of adjacent rocks, unexplored rooms, fissures,

[5] See "Geology of Texas," Vol. 2 (1934), pp. 111, 113, and 127.

minor joints, *et cetera* might store the remaining 92 million barrels of oil. Even if the estimate of the rock removed from the Caverns were 100 per cent too small, there would still be a similarity in volume between the two reservoirs.

Now consider that a regular drilling program calling for 660-foot locations was used in developing the Carlsbad Caverns area. Only a

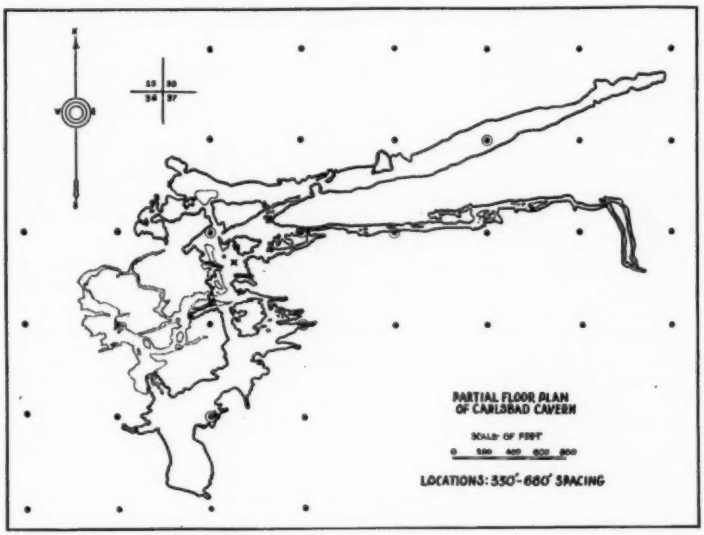


FIG. 1.—Map showing partial floor plan of Carlsbad Caverns. Black dots indicate location of hypothetical wells with respect to rooms, on basis of standard 330–660-foot locations. Only four would penetrate main rooms shown in floor plan.

few of the wells would penetrate the main rooms (Fig. 1). Shooting and acid treatment, as practiced in the average limestone pool, would be required to tap the storage in the various rooms.

The elevator at the Carlsbad Caverns is located 1,320 feet S.-SE. of the NE. corner of Section 36. Using this information, the writer has made standard 330–660-foot locations and shown them on a map of the floor plan of the Caverns. It is interesting to note that only four wells would undoubtedly be drilled into any of the rooms of the Caverns. Some others are located close enough that a crooked hole might, or might not, end in a room. Thus can be seen the conditions under which shooting and acid treatment are likely to aid materially in commercial production.

The type of porosity of which the writer is thinking undoubtedly was produced by subsurface water action. Whether it is of the type described by Beede or of the nature of solution now being perfected by sulphur water in the limestone the writer is unable to state.

If conditions thus pictured caused accumulation in the West Texas limestone fields the time of accumulation was much later than thought by some.

The writer has spent many days in the underground solution channels and caves of southern Indiana, Kentucky, and Texas and can see the possibility that the West Texas producing reservoirs had a similar origin.

DISCUSSION

JOHN L. RICH, University of Cincinnati, Cincinnati, Ohio (written discussion received, April 5, 1938): In connection with Mr. Bybee's paper, the writer desires to call attention to a "fossil" oil pool in limestone, which can be visited and examined. It occurs in some of the zinc mines at Picher, Oklahoma, where a very thick, tarry oil oozes from the limestone into the mine workings, and has caused considerable difficulty in connection with concentrating the ores. The oil seems to come entirely from solution cavities and channels in the limestone, and not from pores. In several places, pieces of the limestone broken from the immediate borders of seeping solution channels showed perfectly hard, dense, blue limestone with no visible trace of oil.

Reference was made to the theory that seems to have gained considerable currency that a period of subaerial exposure and weathering is necessary in order to form solution porosity in a limestone that might later become an oil reservoir. It seems to the writer that subaerial exposure is not necessary for the production of solution cavities in limestone. Artesian circulation of water should accomplish the same result, even at very considerable depths, particularly if the circulation is so vigorous that the water is essentially fresh. The question might be raised: how could the artesian circulation begin unless the limestone were already porous? The reply might be made that as porosity due to solution tends to increase, very small initial openings would gradually be enlarged; furthermore, as limestone is a brittle rock which fractures easily, sufficient jointing might readily be developed along shatter belts or zones of bending to permit the beginnings of artesian circulation. Progressive enlargement of solution channels would then follow as a matter of course.

SUBSURFACE STUDY OF CHEROKEE FORMATION NEAR KANSAS CITY, MISSOURI[1]

GLENN G. BARTLE[2]
Kansas City, Missouri

Recent drilling activities in the vicinity of Kansas City give some additional information concerning the nature of the Cherokee formation underlying this region.

[1] Read by title before the Association at New Orleans, March 18, 1938. Manuscript received, April 24, 1938.

[2] University of Kansas City.

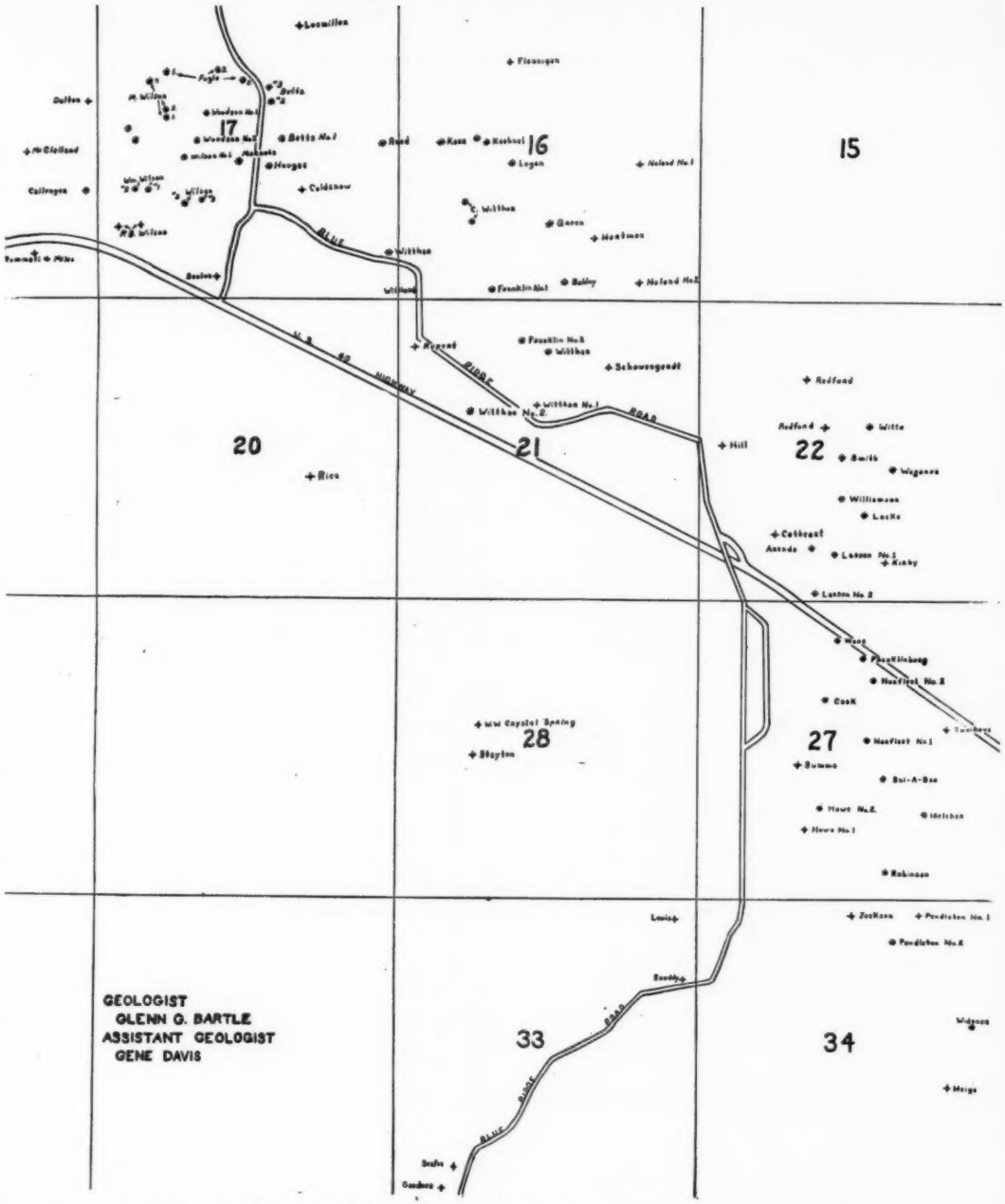
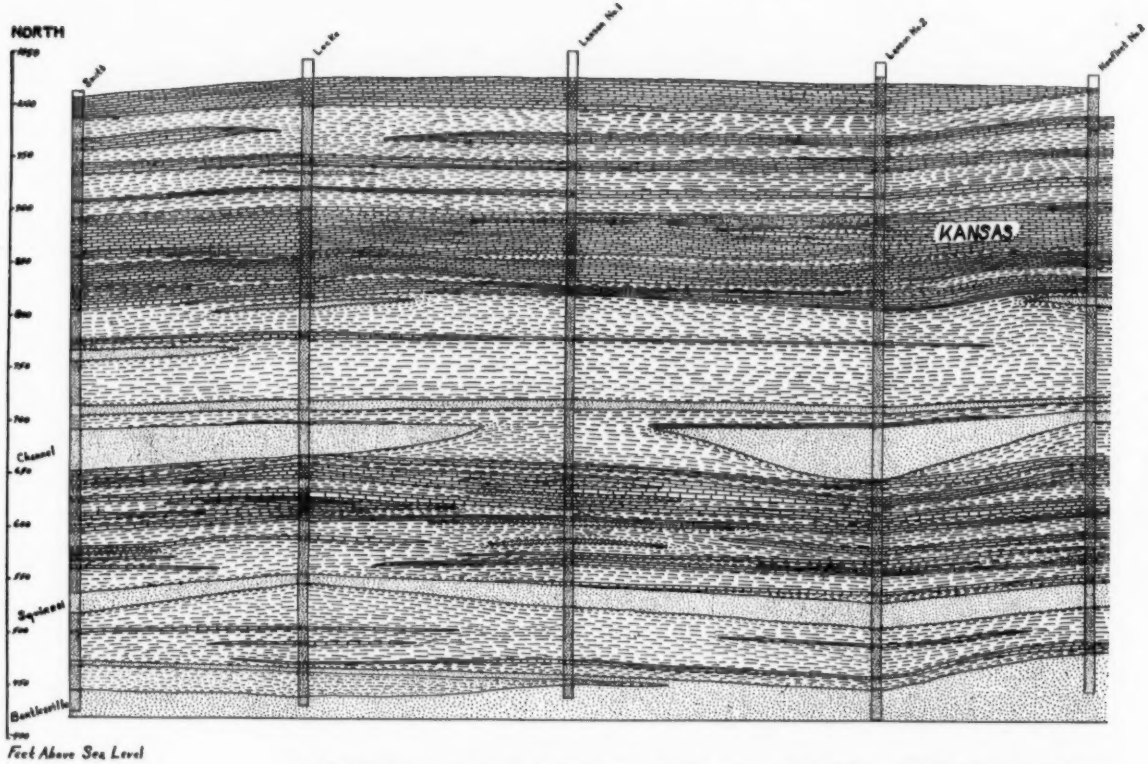
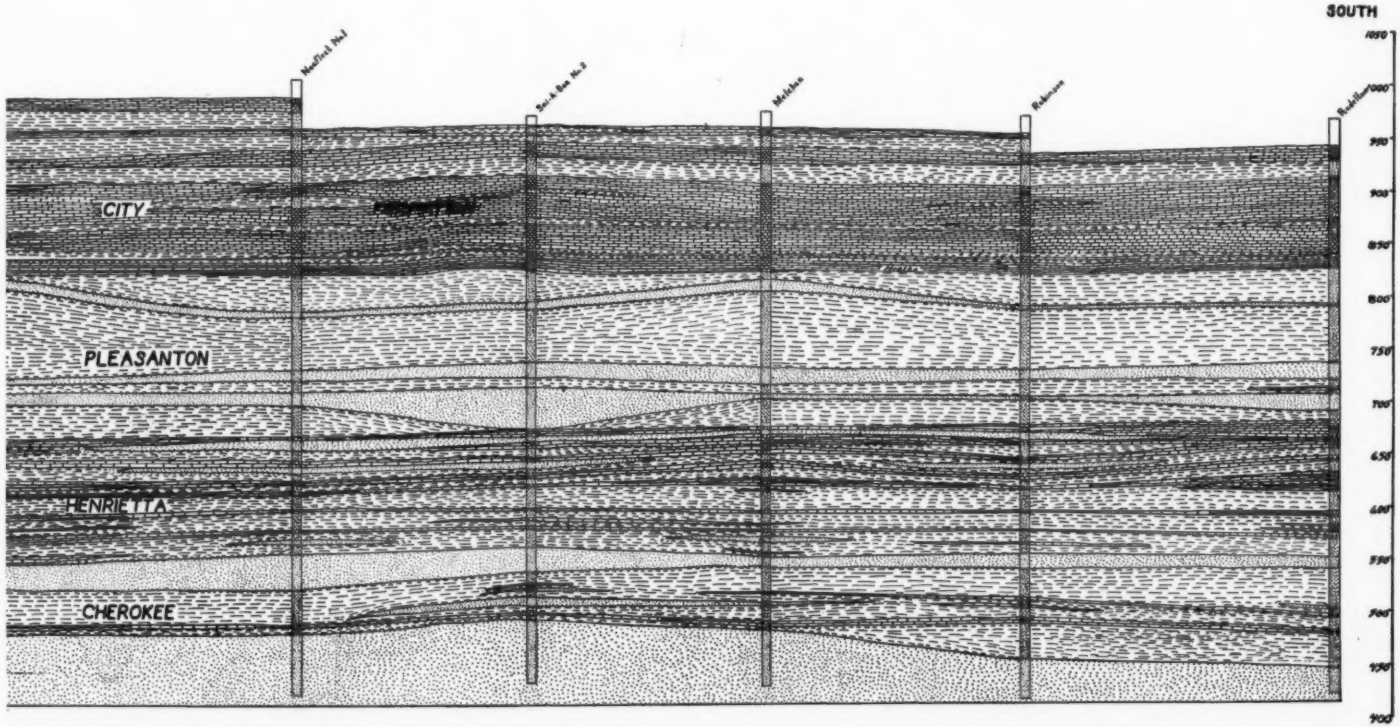


FIG. 1.—Location map of Marotta and Sni-A-Bar gas fields, T. 49 N., R. 32 W., Jackson County, Missouri. Marotta is in northwest and Sni-A-Bar is in southeast part.



NORTH-SOUTH GEOLOGIC SECTION



THROUGH THE SNI-A-BAR GAS FIELD

ONE MILE

GEOLOGIST
GLENN G. BARTLE
ASSISTANT GEOLOGIST
GENE DAVIS

FIG. 2.—North-south geologic section through Sni-A-Bar gas field, showing Cherokee formation.

The Sni-A-Bar gas field is especially important in this connection. This field is in central Jackson County, Missouri, just east of the city limits of Kansas City and just south of the city limits of Independence (Fig. 1). During 1937 approximately fifty wells were drilled in this field. Some of these wells have an initial open flow of more than 4 million cubic feet of gas per day at a depth of less than 600 feet. Wells of this size had not been drilled in the Kansas City region before this time and drilling has been greatly stimulated. Unfortunately, the gas field is so near the city that the land ownership is divided into many small tracts, averaging perhaps 10 acres to each homestead. It has been difficult if not impossible to control the spacing of wells, and more wells have been drilled than is necessary or economically profitable. Although all this is extremely unfortunate from the viewpoint of the operator and of the industry as a whole, it affords an opportunity for a study of the subsurface formations in greater detail than would be possible otherwise.

Before this year, most of the gas production in Missouri and northeastern Kansas has been from the "Big Lake," or Warrensburg, sand and from the "Squirrel" sand.[3] The Warrensburg sand within the Old Pleasanton formation of Missouri, or the Marmaton of Kansas, is now recognized as being the basal member of the Bourbon formation of the Missouri series.[4] Its unconformable nature may be readily recognized in the accompanying cross section (Fig. 2). Formerly most wells have been drilled into the top of the Squirrel, or Prue, horizon and stopped there, but this new deeper drilling provides an opportunity to study the base of the formation. It will be noticed that the Squirrel is fairly uniform in thickness and, at least in the Sni-A-Bar field, is somewhat thin. The Ardmore, or Verdigris, limestone beneath the Squirrel is remarkably extensive and is parallel with the Fort Scott and Pawnee limestones of the Marmaton or Henrietta section.

Just a few feet below the Ardmore limestone is the top of the new producing horizon, called locally the upper Bartlesville. Evidently this sand is of considerable stratigraphic importance, but its distribution is extremely irregular and it is absent in most of the wells drilled in the Kansas City region. As may be seen on the location map, producing wells are in a long "shoestring" trending northwest and southeast. These wells are not only structurally high but are also strati-

[3] Glenn G. Bartle, "The Geology of the Blue Springs Gas Field, Jackson County, Missouri," *Missouri Bur. Geol. and Mines Biennial Report* (1933).

[4] R. C. Moore, "Stratigraphic Classification of the Pennsylvanian Rocks of Kansas," *State Geol. Survey Kansas* (1936).

graphically favorable for gas in the fact that the sand is present. Other surface structures in the vicinity show no sand at this level.

This upper Bartlesville is the approximate equivalent of the shoestring sands in Greenwood County, Kansas, which have been correlated by Weirich and others[5] with the Burbank and Red Fork sands of Oklahoma. The work of Bass[6] and others[7,8] comparing these shoestring sands to the off-shore bars along the Atlantic Coast is well known to the members of this Association. The Welda-Colony gas field and the Garnett-Bush City shoestring in Anderson County, Kansas, show comparable conditions.[9] This is the first time, however, that these deposits have been found as far north and east as Kansas City.

It is understood, of course, that this upper Bartlesville, or Burbank, is younger than the Bartlesville at Bartlesville, or the Bluejacket sand. The lower sand may be present at Kansas City, but it has not been found to be productive of oil or gas.

There has been recent work on the outcropping Cherokee formation of southeastern Kansas by Abernathy.[10] He divides the Cherokee into fifteen cyclothems, but it seems to be difficult to recognize these cyclothems in wells in the Kansas City area. In his subdivisions the Squirrel sand is a zone of sandstone and sandy shale, 1 and 2 of the Mulky cyclothem No. 15, the Ardmore makes up a separate cyclothem No. 13, containing limestone only, and the Bluejacket, or true Bartlesville, is the base of the Bluejacket cyclothem No. 4. The upper Bartlesville, or Burbank, sand is not recognized at the outcrop, but there are local channel sandstones associated with the Weir-Pittsburg coal, in cyclothems 6 and 7.

In this connection it might be interesting to recall the work of David White,[11] who believed, on paleobotanical evidence, that the

[5] T. E. Weirich, "The Burbank Sand of Kansas and Oklahoma," *Oil Weekly*, Vol. 66, No. 10 (August 22, 1932), pp. 25–28.

[6] N. W. Bass, "The Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1313–45.

[7] Bass, Leatherock, Dillard, and Kennedy, "Origin and Distribution of Bartlesville and Burbank Shoestring Sands in Parts of Oklahoma and Kansas," *ibid.*, Vol. 21, No. 1 (January, 1937), pp. 30–66.

[8] Constance Leatherock, "Physical Characteristics of Bartlesville and Burbank Sands in Northeastern Oklahoma and Southeastern Kansas," *ibid.*, Vol. 21 (February, 1937), pp. 246–59.

[9] Homer H. Charles, "Oil and Gas Resources of Anderson County, Kansas," *Kansas State Geol. Survey Bull. 6* (1927).

[10] George E. Abernathy, "The Cherokee Group of Southeastern Kansas," *Guidebook Eleventh Annual Field Conference* (1937), Kansas Geological Society.

[11] David White, "Fossil Flora of the Lower Coal Measures of Missouri," *U. S. Geol. Survey Mon. 37* (1899).

Bevier coal, just above the Ardmore horizon, is definitely Alleghenian in age, but that the Jordan coal, about 174 feet deeper, is Pottsville in age. Unfortunately, the Jordan and Bowen coals which he used as examples are in local basins and can not be correlated accurately with the present section, but it is interesting to note these disconformable sandstones at approximately the right place in the columnar section.

UPPER PALEOZOIC CHINATI SERIES, PRESIDIO COUNTY, TEXAS[1]

JOHN W. SKINNER[2]
Midland, Texas

Recent field work has demonstrated the presence of beds of Strawn, Canyon, and possibly lower Cisco age in the Cieneguita formation of the Chinati Mountains. Faunal evidence was found indicating that the Alta and Cibolo formations are equivalent to the Wolfcamp, Lower Permian, of the Glass Mountains. At its type locality, the Cibolo is overthrust upon thin-bedded limestones of Capitan, Upper Permian, age. Fossils characteristic of the Middle Permian Word formation were found in the dark shale and limestone series west of Shafter, while an assemblage of Capitan fusulinids was collected from the massive yellow limestone at the top of this section. This same yellow limestone is brought to the surface by faulting near the Presidio mine, and most of the silver mined in the area is obtained from this horizon. A detailed paper on the subject is being prepared for presentation at the mid-year meeting of the A.A.P.G. at El Paso in September.

[1] Manuscript received, June 1, 1938.

[2] Humble Oil and Refining Company.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 925-928

DISCUSSION

CUSTER FORMATION OF TEXAS[1]

LEROY T. PATTON[2]
Lubbock, Texas

In an article appearing in the *Bulletin* with the title, "Custer Formation of Texas," Robert Roth[3] proposes a new formation name for the uppermost beds of the Permian of Texas. With much of this article the writer is in agreement. Since the uppermost Permian beds of Texas evidently record a time of varying and shifting conditions of deposition both from time to time and from place to place, including not only land locking and desiccation of seas and parts of seas, but continental deposition of various types, probably including windblown deposits, it is not to be expected that individual units would be continuous over long distances as are marine deposits. The writer has long been of the opinion, therefore, that any attempt to divide these beds into individual units and to correlate those units over long distances would be a misinterpretation of the record. Roth's paper including detailed studies of these sediments is a valuable contribution in support of the concept that these beds should be included under one stratigraphic name. The writer believes, however, that Roth errs in not recognizing the priority of the writer's proposal of the name Peacock formation for these beds, which was made in 1930.[4] The writer defined the Peacock formation as follows. "The part of the Double Mountain Group lying above the Blaine and below the Triassic is designated the Peacock formation in this report."[5]

The Blaine formation as used in this report, and as so stated, contains more than the Blaine of Oklahoma. This was the generally accepted usage of the term in Texas at the time and is the one recognized by the official Survey of the State.[6]

Roth states that the writer's proposal in 1930 does not establish priority for the following reasons: (1) that the name Woodward has priority; (2) that the Quartermaster has priority. The writer does not believe that either of these points is well taken.

The name Woodward was definitely abandoned by its original author, Charles N. Gould, in 1924.[7] A formation name which has definitely been abandoned by its author can not be used to establish priority over a formation name subsequently proposed.

[1] Manuscript received, April 15, 1938.

[2] Department of Geology and Petroleum Engineering, Texas Technological College.

[3] Robert Roth, "Custer Formation of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 4 (April, 1937), pp. 421–72.

[4] L. T. Patton, "The Geology of Stonewall County," *Univ. Texas Bull. 3027* (July, 1930), p. 45.

[5] *Ibid.*

[6] "The Geology of Texas, Vol. 1, Stratigraphy," *Univ. Texas Bur. Econ. Geol. Bull. 3232* (1932), p. 178.

[7] Charles N. Gould, "A New Classification of the Permian Redbeds of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May-June, 1924), p. 325.

In Gould's work on the Panhandle of Texas referred to by Roth, Gould states:[8]

> The Quartermaster formation, which rests conformably upon the Greer, consists for the most part of soft red sandstones and red sandy clays and shales. In Oklahoma, where it is typically exposed, sandstone predominates to such a degree that the formation was originally designated the Quartermaster sandstone, but in the western part of the Panhandle, red shales and clay make up the major portion of the beds, although soft red sandstones are by no means rare.

In this paper Gould also clearly states on p. 13 that his classification is that proposed by himself in *U. S. Geological Survey Water-Supply and Irrigation Paper 148* published in 1905 in which he gives the following classifications.

Formations	*Members*
Quartermaster	
Greer	Mangum Collingsworth Cedartop Haystack Kaiser
Woodward	Chaney Day Creek Whitehorse Dog Creek
Blaine	Shimer Medicine Lodge Ferguson
Enid	

In 1924 Gould[9] abandoned this classification and proposed a new one as follows.

Quartermaster formation
Cloud Chief formation
Day Creek dolomite
Whitehorse sandstone
Dog Creek shale
Blaine gypsum
Chickasha formation
Duncan sandstone

In Gould's abandoned classification he included two formations in addition to the Quartermaster between the Blaine and the Triassic, and in his revised classification he proposes four. Most certainly, therefore, he did not propose the Quartermaster to include "the part of the Double Mountain Group lying above the Blaine formation and below the Triassic." The literature, therefore, does not support the contention that the Quartermaster formation has been proposed for the interval in question and that the name Quartermaster therefore has priority. It might be added also that should it be admitted that either of these do establish priority over the proposal of the Peacock, then by the stronger reason priority over the Custer is established.

[8] *Idem*, "Geology and Water Resources of the Western Portion of the Panhandle of Texas," *U. S. Geol. Survey Water-Supply Paper 191* (1907), p. 15.

[9] Charles N. Gould, "A New Classification of the Permian Redbeds of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May–June, 1924), pp. 322–41.

Roth's article states that the writer's definition of the Peacock formation is "all of the beds from the base of the Swenson gypsum up to the base of the Dockum." This is an inaccurate statement of the writer's definition which has been quoted verbatim in this discussion. The writer's definition does not make the inclusion of the Swenson gypsum a necessary part of the definition. Should it be proved, therefore, that the Swenson gypsum member does not belong to the Peacock formation but to the Blaine, this does not affect the question as to the priority of the proposal of the Peacock as a formation name. There are numerous instances in the literature where similar adjustments have been made in the shifting of beds in the geologic column.

In discussing the Swenson gypsum member, Roth states that the member belongs with the Blaine of Texas "and furthermore is well down in the Blaine." It is difficult to see how this view can be taken.

The Swenson gypsum is the same as the Wagon Yard gypsum. The name Swenson gypsum member was proposed by the writer when his manuscript was first submitted in 1927. The name Wagon Yard was not proposed until 1929. The writer, therefore, retained the name originally proposed when his manuscript was revised in 1930.

On page 462 of Roth's article he states, "Just west of Aspermont there is a very prominent escarpment formed by the 'Wagon Yard' gypsum member of the 'Blaine of Texas.' From south to north the base of the Custer varies from 0 to 30 feet. . . . "

This quotation shows that the Swenson gypsum member is not well down in the Blaine and also that the interval for which Roth proposed the name Custer is substantially the same as the interval for which the writer proposed the name Peacock.

ROBERT ROTH, Wichita Falls, Texas (written comment received, May 12, 1938): The committee on geologic names and correlations for the American Association of Petroleum Geologists ruled in 1937 that the Custer formation as described in 1932 and again in 1937 be classified as a group.

Erratum.—In the article, "Custer Formation of Texas," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 21, No. 4 (April, 1937), p. 466, line 13, for "Blaine" read "Blaine of Texas."

DEEPEST ROCKS AT JACKSON, MISSISSIPPI[1]

WATSON H. MONROE[2]
Washington, D. C.

In January, 1933,[3] I described the rocks from several deep wells in the Jackson gas field, Hinds and Rankin counties, Mississippi, and presented evidence that the deepest rocks encountered are of Paleozoic, probably Carboniferous, age. During the early part of 1937 the State of Mississippi drilled a test well for oil in the Jackson field. This well, deeper than any other in the field, was drilled to a depth of 5,530 feet. With Henry N. Toler, I had the opportunity of studying the cores, cuttings, drillers' log, and

[1] Manuscript received, June 4, 1938. Published by permission of the director, United States Geological Survey.

[2] United States Geological Survey.

[3] Watson H. Monroe, "Pre-Tertiary Rocks from Deep Wells at Jackson, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 1 (January, 1933), pp. 38–51.

Schlumberger electrical log furnished by this well and the results of the study have been published.[4] We agreed that the deepest rocks thus far reached in the gas field are of Lower Cretaceous rather than of Carboniferous age.

As stated in the earlier paper, the available paleontologic evidence was not conclusive. The deeper rocks penetrated by the 1937 test have marked lithologic resemblance to rocks of known Trinity (Lower Cretaceous) age in certain Louisiana wells. Toler and I accordingly decided that this lithologic resemblance provided a safer criterion for estimating the age of the deep rocks in Mississippi than the doubtful paleontologic evidence first used. I, therefore, now wish to change my 1933 correlation of these rocks from Carboniferous to Lower Cretaceous.

[4] W. H. Monroe and H. N. Toler, "The Jackson Gas Field and the State Deep Test Well," *Mississippi State Geol. Survey Bull. 36* (1937), 52 pp.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 929-939

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

REGIONAL GEOLOGY OF THE EARTH EDITED BY K. ANDRÉE, H. A. BROUWER, AND W. H. BUCHER[1]

REVIEW BY R. D. REED[2]
Pasadena, California

Regionale Geologie der Erde (Regional Geology of the Earth), Band 1, *Die Alten Kerne* (The Ancient Coigns), Abschnitt V, "Afrika (ohne Atlässlander und Madagaskar) nebst Arabien" (Africa, excluding the Atlas Lands and Madagascar, but with Arabia). By E. Hennig. 142 pp., 22 figs., 2 pls. Price, RM. 22.

Band 2, *Palaeozoische Tafeln und Gebirge* (Paleozoic Plateaulands and Folded Belts), Abschnitt II, "Northwestern Europe Caledonides." By E. B. Bailey and O. Holtedahl. 76 pp., 16 figs., 2 pls. Price, RM. 14.

Band 2, Abschnitt III, "Mittel- und Westeuropa" (Central and Western Europe). By Hans Becker. 102 pp., 31 figs. Price, RM. 14. Akademische Verlagsgesellschaft M.B.H., Leipzig (1938).

The foregoing publications are the initial installments of a new attempt to synthesize the geology of the earth. As such, they recall earlier attempts, *Handbuch der regionalen Geologie*, and the newer *Geologie der Erde*. As units of discussion the *Handbuch* takes individual countries; the *Geologie der Erde* takes continents; and the present series takes geologic provinces. On this basis the projected work is divided into three volumes.

Volume 1, The Ancient Coigns

Volume 2, The Paleozoic Plateaulands and Folded Belts

Volume 3, The Later Orogenic Belts

Among the differences that serve to distinguish this work from its predecessors the most important, probably, is the one stressed in the preface.

> The distinguishing feature of this work is the attempt to set forth in as small space as possible the development of the geology of the whole face of the earth, with special emphasis on those tectonic and magmatic events from which may be derived significant laws of geological development, with due regard to such features as accompanied and resulted from these processes, such as metamorphism, localization of ores, erosion, and sedimentation. The major facts of stratigraphy are introduced as clues and records of events, not as objects of study for their own sake.

The reference in the passage just quoted to the "face of the earth" apparently suggests the spirit of the present work: in its intent, it will be an up-to-date Suess, produced by the collaboration of an international group of scholars.

The work is intended to be written "in such a way as to be intelligible to the trained geologist without recourse to additional maps or the detailed literature of a given region." The issues under review are measurably successful from this point of view but it may be noted that each of them carries

[1] Manuscript received, May 10, 1938.

[2] The Texas Company.

a list of maps that will be found useful by any readers who may consider the accompanying illustrations insufficient.

> The aim has been to give as complete a picture as possible of present-day knowledge. To that end, gaps and deficiencies in existing knowledge and problems that await solution have been set forth with as much care as was devoted to the critical sifting and presentation of available data.

Completeness and brevity: the combination is likely to make difficult reading. In Hennig's "Africa," the conciseness of the style, the vastness of the area discussed, the complexity of its geography, the difficulty of its stratigraphic names, the uncertainty of their ages, and the rapidity with which the discussion passes from one subject to another before the reader has quite mastered the last one—these or other causes make it a work to study, not to read for pleasure. And yet there are many striking maps and sections, and many clear and interesting discussions of such subjects as the marine Devonian of Cape Colony and the origin of the diamond pipes and the diamonds of Africa; and there is an excellent simplified tectonic map of Africa along with a 12-page discussion of its more important features. There are also some tables that furnish beautiful summaries of Hennig's text and show the relation of the tectonic history to igneous and sedimentary formations and to the different periods of mineralization.

The author's plan excludes the parts of Africa that would be of most interest to oil geologists, but it includes nearly all the areas in which important mining districts are found. To the mining geologists in these districts, unless they are hopelessly uninterested in regional geology, Hennig's volume should prove invaluable. It contains in brief compass a workmanlike synthesis of everything now known about African geology that bears most directly upon their problems.

The second section listed, on northwestern Europe, is written in English and is devoted to the type locality of one of the great orogenic episodes in the geological history of the world, the Caledonian orogeny. This type locality lies in northwestern Europe, in Scotland and Scandinavia chiefly, and has been studied in great detail by both British and Scandinavian geologists for many years. Professors Bailey and Holtedahl here furnish the best available brief synthesis of the facts that they and their colleagues have collected, and present the solutions that have been proposed for the numerous problems that are involved.

The work is illustrated by 16 text figures, mostly maps and sections, and by two plates, one of them a striking tectonic map of the Caledonian belt of Scandinavia. The work begins with a brief introduction, followed by three chapters devoted to the pre-Devonian evolution of Spitzbergen and Bear Island, of the Scandinavian Peninsula, and of the British Isles. Chapter IV treats of the Devonian rocks of the Caledonian belt—that is, of the Old Red sandstone and its associated igneous rocks. The whole post-Devonian history of the region is summarized in Chapter V, pages 56–68. Economic geology (Chapter VI) takes two pages, and the summary in Chapter VII takes five.

The summary points out the absence of the supposedly universal angular unconformity at the base of the Cambrian in the Caledonian geosyncline; the significance of the late pre-Cambrian (?) tillites of Norway; the simplification of Caledonian paleogeography that results from "replacing" Greenland along the northern part of the west boundary of the geosyncline; the

importance of Ordovician vulcanism and orogeny; the multiphase character of the Caledonian orogeny; and the nature of post-Caledonian igneous activity in parts of the Caledonian province.

Section III of Volume 2, Becker's "Central and Western Europe," is probably of greater interest to *Bulletin* readers than the other sections, and is accordingly reviewed at greater length.

Folding movements during the later Paleozoic created a massive mountain system in the heart of Europe. German geologists call it the Variscan Mountains and recognize its remnants in Morocco, in the Iberian Peninsula, in southern Ireland and England, and particularly in continental western and central Europe as far east as Poland. The Donetz folds of southern Russia, though widely separated, are contemporaneous. North of the Variscan belt lies a region that has remained unfolded since the older Paleozoic, the Russian platform, the Fennoscandian shield, and the Caledonian chain. In the south the Variscan belt is bounded by post-Paleozoic Alpine folds that have reworked the included Variscan and older structures beyond recognition. Toward the east the Carpathians, belonging to the Alpine system, override the margin of the Russian platform and thus end Variscan Europe in that direction.

The parts of the Variscan system spared by the Alpine folding constitute the backbone of western and central Europe. Of earlier mountain systems such as the late Algonkian and the Caledonian, only slight traces remain locally in this region. On the other hand, vast stretches are buried under a blanket of Mesozoic and Tertiary, including large amounts of Tertiary volcanic rocks. Tertiary and post-Tertiary planation and dissection, with Pleistocene glaciation of considerable areas, have completed the present landscape.

With a brief introduction, of which the foregoing is a free translation, Professor Hans Becker launches into a hundred-page account of the structure and history of a region that includes most of the geologically better known parts of extra-Alpine Europe. If we were to take away from geological literature the works that have been devoted to different features in this area, we should have left but a small part of the list with which we started. William Smith, Lyell, Werner, Cuvier, Elie de Beaumont, Oppel, Zirkel, Rosenbusch, Cayeux—all these and a great many other eminent geologists have spent most of their lives contributing to the geology of the Variscan region. And the gist of their contributions Professor Becker has tried to compress into the present small volume. Complete success would hardly seem to be possible in such a case, but the author has undeniably succeeded in writing a fascinating account that nobody can afford to miss unless he is willing to master some other, longer account of the same subject.

Chapter I treats of the pre-Variscan structural elements, already mentioned as comparatively few and small. Most interesting, perhaps, are the Caledonian remnants definitely recognized only in Poland, the Ardennes and the massif of Brabant.

Chapter II, on the Variscan system, constitutes about half the book. It tells the history of Variscan Europe before the folding, treats of the detrital deposits from the growing mountains, of the magmatic history of the Paleozoic, of the structure of the Variscan Mountains, of the three principal belts or zones—the sedimentary north zone, the crystalline central zone, and the Moravian east limb—and finally, of the time sequence in the growth of the

mountains. Concerning the magmatic history, Becker points out that the sequence, basalt—squeezed granite (or gneiss)—structureless granite, is repeated just as in the case of the last pre-Cambrian folding; and that the basalt eruptions take place during the formation of the geosyncline, the squeezed granite comes in during diastrophism, the normal granite after the culmination of the folding. This sequence seems to characterize certain types of mountains and may prove to be the best method of defining geosyncline in a restricted sense.

Folding movements began locally during the Middle Devonian and affected different areas at different times; they moved from Bohemia to Saxony, to the Harz, and then to the Rhenish mass. After the Westphalian they attacked the coal belt, created the Eifel fault, and overwhelmed the Spanish region. In Upper Carboniferous the mylonite zones of the Massif Central and of Brittany were produced and most of the Variscan granites were intruded. At the same time came the formation of the depositional basins of the mountain interiors: the "grossfaltung" ("broad-folding" or warping) which created relatively simple ranges out of the heterogeneous elements that preceded. These movements were completed by approximately the middle of the Permian, and from that time begins a new chapter in the history of Variscan Europe.

Chapter III is devoted to "Saxonian Time." It treats of post-Variscan (that is, late Permian to Recent) events in Variscan Europe. At the very beginning, the Variscan mountain system seems to have broken up into a series of positive and negative areas that were apparently independent of the older, Variscan structure. Among the positive areas may be mentioned the Polish Central ranges, the Bohemian massif with the Vindelician land, the Harz (dating only from the end of the Trias), the Ardennes-Rhenish massif, the Schwarzwald, Vosges, the Massif Central, Maures, and the Spanish Meseta. Only the Vindelician land has since completely disappeared.

The break-up of the Variscan system was brought about by attacks from two sides: from the south, where the Tethyan geosyncline dates from the Trias; from the north, where in a belt stretching from South England to Poland the Saxonian basin developed and became the site of deposition of the best known Mesozoic and Tertiary strata of the world, and also the site of the late Mesozoic-Tertiary Saxonian orogeny. The two basins, Tethyan and Saxonian, have deposits that are contemporaneous but widely different in facies; the latter differs also in that it lacks the "geosynclinal" vulcanism that is well represented in the former. In Professor S. von Bubnoff's terminology, it is a "labile shelf." The two basins were sometimes connected across the Paris basin, the Fränkische basin of central Germany, and others.

The history of Central Europe during the time of Permo-Triassic aridity is compressed into a few pages, illustrated by stratigraphic tables and (as always) by paleogeographic maps. Jurassic, Cretaceous, Older and Newer Tertiary follow rapidly, and then comes a longer account of the Saxonian mountain-making. Though contemporaneous with Alpine orogeny, the Saxonian disturbances differ fundamentally both from it and from the Variscan folding that took place earlier on the site of the Saxonian basin. Thus, the Saxonian folding merely broke Variscan elements into blocks that were raised or depressed but never remoulded into new structural forms. Even in the post-Variscan blanket the folding generally has produced "fault-folds."

Unbroken anticlines and synclines are not very common, though the most strongly uplifted and downsunken elements line up into more or less irregular anticlinal and synclinal belts. In general, faults are commoner where the Saxonian blanket is thin, folds where it is thick; but the upfolds in the areas of thicker blanket are often interrupted by narrow horsts, related to upthrusts or even to "domes" of the Zechstein salt deposits. Though most of the Saxonian structures are of compressional type, tensional features also occur.

The Saxonian movements began locally, as in South Poland, at the end of the Triassic; they affected great areas in uppermost Jurassic and became even more widely active during Upper Cretaceous and later.

"The Saxonian folding is not a mere accompaniment of the Alpine orogeny. In structural plan, in age of movements, and in type of structure, it is entirely independent." Northwest-southeast strike, and movement toward the southwest are dominant but not universal. In some places, such as southern France and the area of the "Mittelmeer-Mjösen Zone," the Alpine orogeny has interfered sufficiently to produce striking complications. The independence of the Saxonian folding is further indicated by the accompanying vulcanism, which varied so strikingly that Becker considers the discovery of regularities, either in its occurrence in time and place or in its chemistry, to be difficult if not impossible. Even the general rule that its latest eruptions are basaltic is not without exceptions.

Chapter IV, on the most recent developments, deals interestingly but briefly with physiographic evolution, the Ice age, and post-glacial events.

Chapter V, on mineral deposits, though less than two pages long, gives a useful summary of the relation between important European mineral deposits and the structural history of the regions in which they are found. It may be abstracted as follows.

Central and Western Europe owes most of its mineral deposits to the Variscan mountain-making. The oldest Variscan product is red ironstone, a hydrothermal accompaniment of Devonian diabase in the Rhenish massif and in the Harz. The Variscan granites furnished contact deposits, and the rich veins of tin, lead, silver, iron, and fluorspar found in nearly all Variscan areas, worked for centuries, and still not completely exhausted. Before all, the region owes to the Variscan mountains its coal deposits, which accumulated in their marginal or interior basins. A second important group of deposits begins with the Zechstein, which furnishes the Kupferschiefer (sole important copper ores of Central and Western Europe) and the inexhaustible salt and potash deposits of North Germany. Most German petroleum is supposedly late Permian or Mesozoic, though the source-rock is not definitely known. Like its accessory product, asphalt, it occurs in different horizons from the Zechstein to the Tertiary but as a secondary product. After the Triassic, ore-bearing solutions brought lead and zinc to the Muschelkalk of Upper Silesia and Wiesloch (Rhine graben) and to the Paleozoic limestones along the northern margin of the Rhenish massif. Most important of the Mesozoic deposits are the Jurassic oölitic iron ores of Lorraine, Swabia, and Poland, and similar Cretaceous ores in the Harz. Tertiary lignites are widespread, and numerous thermal and mineral springs exist as a gift of Tertiary vulcanism. Petroleum is found in the Tertiary of the Rhine graben.

The brief summary, in Chapter VI, discusses several of the fundamental

problems in Variscan Europe: the magmatic cycle, the origin of the detritus of the Variscan geosyncline, the problem of "consolidation" by orogenic processes, the constancy of positive and negative areas, and several others. Answers to most of these problems, Becker believes, are involved with subterranean phenomena not accessible to observation and belonging in the last analysis to geophysics rather than to regional geology.

As is true of all geological books appearing currently in Germany, the prices of those under review are so high that the distribution is likely to be less wide than it should be. This condition is no doubt unavoidable but is nevertheless unfortunate.

PALAEOZOIC FORMATIONS IN THE LIGHT OF THE PULSATION THEORY, VOL. III, CAMBROVICIAN PULSATION SYSTEM[1]

BY AMADEUS W. GRABAU

REVIEW BY BYRON N. COOPER[2]
Wichita, Kansas

Palaeozoic Formations in the Light of the Pulsation Theory, Vol. III, *Cambrovician Pulsation*. By A. W. Grabau. 850 pp., 58 figs., 3 pls., 1 map, 6 correlation charts. $9\frac{1}{8} \times 6\frac{1}{2}$ inches. Cloth. Published by The National University of Peking. Price: Chinese, $15.00; U. S., $5.50; Great Britain and Colonies, 20/–. Sales agent, Henri Vetch, The French Bookstore, Peking, China.

In this volume, Grabau enters the controversial field of Ozarkian-Canadian stratigraphy. Since Ulrich's startling pronouncements of 1911, many geologists have sought to erase the problems and solutions of Cambrian-Ordovician stratigraphy as voiced by that master stratigrapher. Despite a barrage of criticism which has lasted for over a quarter of a century, it must be admitted that most of Ulrich's postulates have withstood the uncompromising test of time. However, it has become apparent recently that Ulrich has been guilty of serious inconsistency in the correlation and classification of certain Cambrian-Ordovician formations. Indeed, the fate of his claims for the systemic rank of the Ozarkian and Canadian divisions depends largely upon the manner in which these inconsistencies are removed. Bridge's recent work suggests that these divisions are not worthy of systemic rank.

Grabau offers a sane, and yet a very radical, escape from the Ozarkian-Canadian debacle. His suggestions incorporate the general precepts of Ulrich, and they satisfactorily remove many of the objections commonly voiced to the latter's work. Grabau's conclusions regarding Cambrian-Ordovician stratigraphic taxonomy may be summarized as follows.

1. The Upper Cambrian of Ulrich should be referred to the Middle Cambrian series, which series terminates the Cambrian Pulsation system. That part of the type St. Croixan series which lies below the *Prosaukia* zone of the Franconia formation is Middle Cambrian in age.

2. The old Middle Cambrian epoch witnessed a regression of the epicontinental seas which had advanced earlier in Cambrian time. Therefore, the Cambrian should be delimited so as to end with the Middle Cambrian regression of the seas.

[1] Manuscript received, May 14, 1938.

[2] University of Wichita.

3. An erosion interval of inter-systemic significance exists between beds of Nolichucky age and younger strata, as postulated by Ulrich.
4. Ulrich's Ozarkian and Canadian systems are demoted to the rank of series within a single system, the *Cambrovician Pulsation system.*
5. The Upper Ozarkian Chepultepec beds are equivalent to the Lower Canadian Stonehenge formation. Therefore, the hiatus which Ulrich postulates to exist between his Ozarkian and Canadian in the Appalachian Mountain region does not exist.
6. The Cambrovician Pulsation system is composed of two series. The lower division, the Ozarkian transgressive series, includes Ulrich's Ozarkian, his Lower Canadian, and that part of the Upper Mississippi Valley St. Croixan section which lies above the *Ptychaspis* zone of the Franconia formation. The upper division, the Shenandoan regressive series, includes Ulrich's Middle and Upper Canadian and also his basal Ordovician Everton formation.
7. Ulrich's Lower and Middle Ozarkian are equivalent to the upper part of the St. Croixan series.
8. An unconformity of inter-systemic significance intervenes between the Cambrovician and younger beds. Except in Missouri, this break corresponds to the Canadian-Ordovician break of Ulrich.

In Chapters I-IX and Appendixes II, V, and VI the Cambrian-Ordovician strata of the following North American areas are discussed: Southern Appalachian geosyncline, Maryland and southern Pennsylvania, New York, New Jersey, Ozark region, southern Oklahoma and central Texas, Upper Mississippi Valley region, Canadian Rockies, McKenzie River Valley, Alaska, and Greenland. Another 300 pages are devoted to the description and classification of Cambrovician rocks of Bolivia, Argentina, South Africa, Australia, New Zealand, Antarctica, India, Persia, Asia Minor, China, Manchoukuo, Burma, Korea, Siberia, and Nordland. A brief review of the stratigraphy of equivalent beds in the British Isles is given in Appendix III.

Approximately 80 pages are devoted to tabulation of the geographic distribution and stratigraphic range of more than 1,600 species of Cambrovician fossils. The paleontological data in these summary tables form the basis of most of Grabau's correlations. They are a great contribution to geological literature.

Appendixes I-II and V-VI are digests of recent stratigraphic and paleontological papers by Ulrich and Foerste, Stose and Jonas, Stauffer, Ruedemann and Wilson, C. P. Ross, and Deiss, which papers appeared in print while the body of Grabau's manuscript was in press. Many maps, correlation tables, cross sections, and columnar sections complete the extensive report.

Grabau has made a real contribution to geological literature in this compilation of the stratigraphic and paleontological details of Ozarkian-Canadian rocks of the world. Geologists of the United States will find special interest in the description of the many Asiatic sections. This book will serve as a substitute for scores of foreign papers which are not usually available to geologists in this country. The reference value of the work is enhanced by two well integrated indexes.

The form of the book, however, leaves much to be desired. Many references are incomplete and misleading. Because a consistent form of sub-heading designations is not followed, the numerous outline sections are difficult to follow. Misspelling of numerous stratigraphic names tends to confuse the reader. There is no general bibliography. The volume could have been considerably shortened by eliminating numerous repetitions and discussions of subjects not directly related to Cambrovician stratigraphy.

Now that the case of the Ozarkian-Canadian issue has been restated in

modified form and the principal errors of Ulrich's classification satisfactorily exposed, perhaps geologists of many factions will find it less difficult to come to some sort of agreement. Although the classification of Grabau is very radical in its departure from the conventional taxonomic mold, one can not avoid the conclusion that it is at least more logical and consistent than the present classification. Although this volume deserves the attention of geologists in its own right, it can not be denied that the work is a vindication for Ulrich.

Grabau is to be complimented for his open-mindedness with reference to the ultimate Cambrian-Ordovician classification. After stating his reasons for combining the Ozarkian and Canadian into one system, he admits that each of these two divisions may be worthy of separate systemic rank by concluding:

> Whether these conflicting evidences will eventually be harmonized, remains to be seen, although it must be confessed that perhaps the preponderance of evidence points to prolonged interruption of sedimentation at the end of Upper Cambrian time, with more or less erosion preceding the advent of the sea in Tremadocian time.
>
> This would correspond to the succession of events recognized by Ulrich in the typical Ozark System of the Southern United States, and may eventually necessitate the interpolation of his Ozarkian System as an independent Pulsation System between the Middle Cambrian and the Canadian, in which case the Cambrovician System as here used must be divided into two systems, the Ozarkian . . . and the Canadian. . . .

RECENT PUBLICATIONS

AUSTRIA

*"Ueber die Möglichkeiten von Erdolvörkommen in der nordalpinen Flyschzone Oesterreich" (On the Possibilities of Petroleum Occurrences in the North Alpine Flysch Zone of Austria), by Hermann Vetters. *Bohrtechniker-Zietung* (Vienna), Heft 5, Jahr. 56 (May, 1938), pp. 65–73. Contains geological map and cross sections.

AUSTRALIA

**Geological Map of Part of the West Kimberley Division, Western Australia.* Prepared on behalf of the Freney Kimberley Oil Company by Arthur Wade. In colors. 4 sheets, 31×25 inches. Published by authority of the Minister of State for the Interior. Canberra (1937).

CALIFORNIA

*"Fauna from the Markley Formation (Upper Eocene) on Pleasant Creek, California," by Bruce L. Clark. *Bull. Geol. Soc. America*, Vol. 49, No. 5 (May 1, 1938), pp. 683–730; 4 pls., 1 fig.

*"Coalinga District Eocene Production," by Gerard Henny. *California Oil World* (Los Angeles), Vol. 31, No. 10 (May 20, 1938), pp. 3–8.

*"Bibliography of the Geology and Mineral Resources of California, for the Years 1931 to 1936, Inclusive," by Solon Shedd. *California Department of Natural Resources, Division of Mines* (San Francisco) *Bull. 115* (May, 1938). 121 pp. Price, $1.25.

*"Wheatland Formation and Its Relation to Early Tertiary Andesites in the Sierra Nevada," by B. L. Clark and C. A. Anderson. *Bull. Geol. Soc. America*, Vol. 49, No. 6 (June 1, 1938), pp. 931–56; 4 pls., 2 figs.

COLORADO

*"Geology and Oil Resources of Eastern Colorado," by F. M. Van Tuyl, Ben H. Parker, and Willis H. Fenwick. *Mines Magazine* (Denver), Vol. 28, No. 5 (May, 1938), pp. 177–85.

*"The Greasewood Oil Field—Weld County, Colorado," by Charles S. Lavington. *Ibid.*, pp. 186–88.

*"The Gulf U. P. Risser and Pipe Spring Tests, Kiowa and Bent Counties, Colorado," by W. A. Waldschmidt and A. B. Van Tine. *Ibid.*, pp. 189–91.

*"Geology of Wilson Creek Dome, Rio Blanco and Moffat Counties, Colorado," by E. H. Hunt. *Ibid.*, pp. 192–95.

*"The No. 1 Hostetter Test—Kiowa County, Colorado," by Boris V. Lerke. *Ibid.*, pp. 196–97.

*"Debeque Anticline—Mesa County, Colorado," by V. J. Hendrickson. *Ibid.*, pp. 198, 202.

*"Divide Creek Anticline—Garfield and Mesa Counties, Colorado," by Charles S. Lavington. *Ibid.*, pp. 203–06.

*"Point Lookout Gas Structure—Montezuma County, Colorado," by V. J. Hendrickson. *Ibid.*, pp. 207–09.

*"Selected Bibliography on the Geology and Petroleum Possibilities of Colorado," compiled by J. Harlan Johnson. *Ibid.*, pp. 210–12, 224–28.

CUBA

**Field Guide to Geological Excursion in Cuba*, by R. H. Palmer. 20 pp. "This pamphlet has been prepared for the use of the members of the American Association of Petroleum Geologists who take part in the Cuban Excursion that follows the annual convention held at New Orleans in March, 1938. It is descriptive of the geology along the route of several trips that have been planned. The trips have been selected to provide a general idea of one of the major geological units of Cuba. This unit occupies the Province of Habana and the eastern half of the Province of Matanzas. The area covered has been extended to the east beyond the unit in question to include a part of an area that is believed to have petroleum possibilities." Published by Carasa Y Ca., S. en C., Teniente Rey 12–14, Habana.

FRANCE

*"Considerations sur les Recherches de Petrole en Languedoc" (Considerations on the Search for Petroleum in Languedoc), by J. Estival, Dreyfuss, and Thoral. *Revue Petrol.* (Paris, May 13, 1938), pp. 605–07.

GENERAL

*"An Equilibrium Theory of Proration," by Joseph E. Pogue. *Petrol. Tech.* (Amer. Inst. Min. Met. Eng., New York), Vol. 1, No. 2 (May, 1938), *Tech. Paper 904.*

*"Desalting Crude Oils," by Gustav Egloff, Edwin F. Nelson, D. C. Maxutov, and Charles Wirth, III. *Ibid.*, *Tech. Paper 915.*

*"Behavior of Contents of High-Pressure Reservoirs," by Eugene A. Stephenson. *Ibid.*, *Tech Paper 916.*

*"Gas Caps, Their Determination and Significance," by P. P. Gregory. *Ibid.*, *Tech. Paper 917.*

*"Intensive Weighting of Petroleum Drilling Muds with Galena," by Henry Emmett Gross. *Ibid.*, *Tech. Paper 918.*

*"Pressure Distribution in Oil and Gas Reservoirs by Membrane Analogy," by Aaron J. Miles and Eugene A. Stephenson. *Ibid., Tech. Paper 919.*

*"The Origin of Petroleum," by E. Berl. *Ibid., Tech. Paper 920.*

*"Aerial Survey in Exploration Work," by G. Scherpbier and J. Krebs. *Jour. Inst. Petrol. Tech.*, Vol. 24, No. 174 (London, April, 1938), pp. 225–32; 5 figs.

*"*Public Administration Organizations, A Directory, 1938–1939.* 184 pp. 7×9¾ inches. Cloth. Public Administration Clearing House, 1313 60th St., Chicago. Price, $1.50.

*"Origin of Composite and Incomplete Internal Moulds and Their Possible Use as Criteria of Structure," by James S. Cullison. *Bull. Geol. Soc. America*, Vol. 49, No. 6 (June 1, 1938), pp. 981–88; 1 pl.

GEOPHYSICS

"Geophysical Abstracts 89, April-July, 1937," compiled by W. Ayvazoglou. *U. S. Geol. Survey Bull. 895-B* (1938), pp. i-ii, 43–92. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.10.

KANSAS

*"Oil and Gas Resources of Western Kansas," by Walter A. Ver Wiebe. *Bull. Univ. Kansas* (Lawrence), Vol. 39, No. 7 (April 1, 1938), *Min. Resources Cir. 10.* 179 pp., 31 county maps.

KENTUCKY

*"Outlines of Kentucky Geology," by Arthur C. McFarlan. *Pan-Amer. Geol.* (Des Moines), Vol. 49, No. 6 (June 1, 1938), pp. 267–91.

*"Stratigraphic Relationships of Lexington, Perryville, and Cynthiana (Trenton) Rocks of Central Kentucky," by A. C. McFarlan. *Bull. Geol. Soc. America*, Vol. 49, No. 6 (June 1, 1938), pp. 989–96; 1 pl., 1 fig.

LOUISIANA

*"Lafitte—World's Deepest Major Field," by Michel T. Halbouty. *World Petrol.* (New York), Vol. 9, No. 5 (May, 1938), p. 44.

**Thirteenth Biennial Report Dept. Conservation, State of Louisiana, 1937–1938* (New Orleans, 1938). Contains report of Minerals Division and report of the Geological Survey. Includes map showing oil, gas, and sulphur fields, salt domes.

MICHIGAN

**Michigan Geology-Progress Bibliography, Pt. II*, by Duncan Stewart, Jr. Michigan State College Agriculture and Applied Science (East Lansing, May, 1938). 20 mim. pp. 355 items from *Econ. Geol.*, 1905–1937, *Bull. Geol. Soc. America*, 1890–1937, *Proc. Geol. Soc. America*, 1933 (1934)–1936 (1937), *Jour. Sed. Petrol.*, 1931–1937, *Contrib. Museum Geol. Univ. Michigan*, 1934–1937, *Contrib. Museum Paleon. Univ. Michigan*, 1928–1937, and errata and additions, including papers for 1937 (Pt. 1).

MONTANA

*"Dating Cretaceous-Eocene Tectonic Movements in Big Horn Basin by Heavy Minerals," by Marcellus H. Stow. *Bull. Geol. Soc. America*, Vol. 49, No. 5 (May 1, 1938), pp. 731–62; 2 pls., 3 figs.

NEBRASKA

"Geology and Ground-Water Resources of South-Central Nebraska, with Special Reference to the Platte River Valley between Chapman and Gothenbury," by A. L. Lugn and L. K. Wenzel. *U. S. Geol. Survey Water-Supply Paper 779* (1938). 242 pp. 16 pls., 21 figs. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.70.

*"The Miocene of Western Nebraska," by C. Bertrand Schultz. *Amer. Jour. Sci.* (New Haven, Connecticut), Ser. 5, Vol. 35, No. 210 (June, 1938), pp. 441–45.

OKLAHOMA

**Gorman's Petroleum Directory of Oklahoma, 1938.* The latest edition whose purpose is "to list all the companies and individuals in the State of Oklahoma, who are engaged in the production of petroleum or dealing in petroleum properties." Also includes drilling contractors, geologists, and abstracters. 160 pp. $4\frac{1}{2}\times7\frac{1}{2}$ inches. Paper. B. R. Gorman, Box 385, Tulsa, Oklahoma. Price, $1.00.

*"A Study of Surface Rocks from Calvin Sandstone to Permian through Township Six North to Township Ten North, Hughes, Seminole, and Pottawatomie Counties, Oklahoma." Shawnee Geological Society Field Conference (1938). Itinerary of the field trip, two correlation charts. 13 mim. pp.

OREGON

*Stratigraphy and Mollusca of the Eocene of Western Oregon," by F. E. Turner. *Geol. Soc. America Spec. Paper 10* (June, 1938). 130 pp., 7 figs., 22 pls., 8 tables.

*Geology of the Lower Columbia River," by Edwin T. Hodge. *Bull. Geol. Soc. America*, Vol. 49, No. 6 (June 1, 1938), pp. 831–930; 25 figs., 12 pls.

ROCKY MOUNTAIN REGION

*"Working Hypothesis for the Physiographic History of the Rocky Mountain Region," by Wallace W. Atwood and Wallace W. Atwood, Jr. *Bull. Geol. Soc. America*, Vol. 49, No. 6 (June 1, 1938), pp. 957–80; 4 figs., 12 pls.

RUSSIA

*"Neue Erdölvorkommen in europäischen Teil der Sowjetunion" (Recent Oil Discoveries in the European Part of the Soviet Union), by N. Polutoff. *Die Ostwirtschaft* (Berlin), Jg. 1938, Nr. 3 (March, 1938), p. 41.

UGANDA

**Annual Report of the Geological Survey Department for the Year ended 31st December, 1937.* Printed by the Government Printer, Uganda (1938). Price, Shs. 3. Contains provisional geological map of Uganda, 26×26 inches.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 940-945

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Robert Lewis Augenthaler, Houston, Tex.
Kenneth H. Crandall, Gage Lund, Earle R. Wall
Herman Carroll Becker, Tulsa, Okla.
Andrew Gilmour, John L. Ferguson, Jess Vernon
Oscar Lafayette Bocock, Corsicana, Tex.
William C. McGlothlin, John C. Miller, Joseph M. Patterson
J. Daviss Collett, Jr., Houston, Tex.
Alfred Gray, Olaf F. Sundt, Robert N. Kolm
Harris Cox, Dallas, Tex.
Barney Fisher, Cecil H. Green, Eugene McDermott
Edgar James Daniel, Haifa, Palestine
F. E. Wellings, N. E. Baker, F. R. S. Henson
William Lloyd Effinger, Ibague, Colombia, S.A.
G. C. Gester, Lawrence L. Tabor, Thomas J. Etherington
Howard F. Gemmell, Pittsburgh, Pa.
C. H. Dresbach, E. A. Eckhardt, L. L. Nettleton
Heinrich Louis Koch, Centralia, Ill.
K. H. Schilling, Ernest Guy Robinson, Virgil R. D. Kirkham
Francis Henry McGuigan, Abilene, Tex.
Cary P. Butcher, John I. Moore, W. D. Anderson
Louis Henry Morris, Houston, Tex.
John C. Miller, Louis A. Scholl, Jr., W. W. Patrick
Lincoln Ridler Page, Midland, Tex.
Alfred C. Lane, W. H. Emmons, Clinton R. Stauffer
Jesse Elmore Simmons, Midland, Tex.
D. D. Christner, Charles D. Vertrees, E. Russell Lloyd
Knowles Burdette Smith, Notre Dame, Ind.
C. Dwight Avery, J. N. McGirl, William J. Sherry

FOR ASSOCIATE MEMBERSHIP

Harry Berkeley Allen, West Los Angeles, Calif.
U. S. Grant, E. K. Soper, J. Edmund Eaton
Jack M. Barton, Enid, Okla.
Charles E. Decker, V. E. Monnett, G. E. Anderson
Dwight Lyman Becker, Fort Worth, Tex.
W. D. Anderson, J. F. Hosterman, Dollie Radler Hall

William Norfolk Booth, San Francisco, Calif.
Charles E. Weaver, Theodore Chapin, Mason L. Hill
Luther Weldon Calahan, Shreveport, La.
G. W. Schneider, C. L. Moody, C. E. Decker
Harold August Chun, Mont Belvieu, Tex.
Sidney A. Judson, Olaf F. Sundt, Roderick A. Stamey
Lauren Tenney Conger, Fort Worth, Tex.
Norman L. Thomas, M. E. Roberts, Theron Wasson
Warren LeRoy Constant, Houston, Tex.
James W. Kisling, Jr., J. F. Hosterman, A. R. Denison
Russell Calvin Cooper, Wichita, Kan.
L. W. Kesler, Glen C. Woolley, Ward R. Vickery
James Alfred DeLong, Enid, Okla.
Jack M. Copass, J. Lawrence Muir, Dollie Radler Hall
Conrad Leopold Dorn, Whittier, Calif.
William S. W. Kew, Herschel L. Driver, W. H. Holman
Virgil G. Feather, Bartlesville, Okla.
William Henry Courtier, Hugh W. O'Keeffe, T. E. Weirich
John M. Fouts, Jr., Dallas, Tex.
Robert H. Cuyler, Fred M. Bullard, Hal P. Bybee
Joseph Powers Gill, Ardmore, Okla.
Linn M. Farish, F. A. Bush, Charles E. Clowe
William Mark Krum, Maracaibo, Venezuela, S.A.
Charles E. Decker, V. E. Monnett, W. H. Emmons
James Franklin Michael, Shawnee, Okla.
Jack M. Copass, J. Lawrence Muir, Dollie Radler Hall
Arthur Barrett Miller, Houston, Tex.
Dave P. Carlton, C. M. Nevin, C. R. Church, Jr.
Richard H. Pence, Lynwood, Calif.
Joseph S. Hook, J. R. Pemberton, Theodore Chapin
Charles Edwin Riddell, Bakersfield, Calif.
Drexler Dana, Everett C. Edwards, A. O. Woodford
Kenneth A. Robertson, Pasadena, Calif.
F. M. Van Tuyl, J. Harlan Johnson, Ben H. Parker
Ralph Burdette Senseman, Beeville, Tex.
Fred P. Shayes, J. M. Hancock, D. G. Barnett
Francis Marion Setzer, Houston, Tex.
Louis C. Roberts, Jr., A. L. Selig, Shirley L. Mason
John A. Veeder, Shawnee, Okla.
Bruce H. Harlton, Dollie Radler Hall, A. R. Denison
Leon Robert Vesely, Houston, Tex.
James W. Kisling, Jr., Dale L. Benson, A. E. Getzendaner
Robert N. Watson, Brownwood, Tex.
Raymond Sidwell, W. I. Robinson, M. A. Stainbrook

FOR TRANSFER TO ACTIVE MEMBERSHIP

Avary Hunt Alcorn, San Antonio, Tex.
Robert N. Kolm, Philip S. Schoeneck, Rae Preece
Arthur Y. Barney, Charleston, W. Va.
Victor Cotner, Charles Brewer, Robert Lafferty

George W. Baughman, Wichita, Kan.
R. G. Moss, E. Gail Carpenter, D. A. McGee
Robert W. Beck, Saginaw, Mich.
B. F. Hake, H. F. Moses, E. O. Markham
Douglas Edwards Bell, Houston, Tex.
L. T. Barrow, L. P. Teas, F. W. Rolshausen
Dan Eugene Boone, Houston, Tex.
E. O. Buck, Wallace C. Thompson, V. E. Monnett
Kendall E. Born, Nashville, Tenn.
T. E. Weirich, George M. Hall, B. Coleman Renick
Frank M. Brooks, Wichita, Kan.
W. B. Wilson, Anthony Folger, L. W. Kesler
Hillard William Carey, Houston, Tex.
R. A. Stamey, J. C. Montgomery, Lon D. Cartwright, Jr.
Weldon Emerson Cartwright, Shreveport, La.
K. A. Schmidt, Morgan J. Davis, Cary P. Butcher
John Willard Clark, Dallas, Tex.
Lewis W. MacNaughton, Ed W. Owen, Fred B. Plummer
William Henry Corey, Maracaibo, Venezuela, S.A.
W. S. W. Kew, M. G. Edwards, Wayne Loel
Everett Eaves, Shreveport, La.
G. D. Thomas, L. R. McFarland, Hugh Lee Burchfiel
Clinton Engstrand, Pratt, Kan.
Homer H. Charles, R. J. Riggs, L. M. Clark
Paul J. Fly, Houston, Tex.
L. T. Barrow, L. P. Teas, D. P. Olcott
Melville Weston Fuller, Mattoon, Ill.
L. Murray Neumann, L. F. McCollum, D. C. Nufer
John Taylor Galey, Pittsburgh, Pa.
W. T. Thom, R. E. Sherrill, John R. Sandidge
Julius Benjamin Garrett, Jr., Houston, Tex.
Merle C. Israelsky, A. L. Selig, H. V. Howe
Morris Earle Halsted, Bunkie, La.
James W. Kisling, Jr., J. F. Hosterman, A. R. Denison
Wynne K. Hastings, Fairfield, Ill.
W. B. Wilson, Hellmut Klaus, W. E. Bernard
Walter Wendell Schell Johns, Tulsa, Okla.
E. F. Schramm, John N. Troxell, H. H. Arnold, Jr.
Thomas Carroll Wilson, Pittsburgh, Pa.
J. E. Billingsley, William O. Ziebold, Robert C. Lafferty
Bruno Oscar Winkler, Palembang, Sumatra, N. E. I.
Executive Committee action.—Constitution, Article III, Section 3
Ray Youngmeyer, Tyler, Tex.
J. F. Hosterman, A. R. Denison, Dollie Radler Hall

ADDITIONAL LIST FOR ACTIVE MEMBERSHIP

Gordon I. Atwater, Houston, Tex.
Wallace C. Thompson, A. P. Allison, Lon D. Cartwright, Jr.
Jerome Joseph O'Brien, Dallas, Tex.
R. J. Forsyth, E. K. Soper, U. S. Grant

FOR ASSOCIATE MEMBERSHIP

Benjamin Alvarado, Minneapolis, Minn.
W. H. Emmons, Clinton R. Stauffer, Carey Croneis
Jed B. Maebius, Saginaw, Mich.
B. F. Hake, R. L. Belknap, R. B. Newcombe
Hugh E. Prokesh, Ponca City, Okla.
L. F. Athy, G. C. Clark, S. K. Clark
George Kenneth Robertson, Pasadena, Calif.
Max L. Krueger, E. B. Noble, Louis N. Waterfall
Harvey Jefferson Simmons, Jr., Olean, N. Y.
Chester D. Whorton, R. C. Lane, H. Rogers Van Gilder
Rex Harding White, Dallas, Tex.
Perry R. Love, Clarence M. Sale, Verner Jones

FOR TRANSFER TO ACTIVE MEMBERSHIP

Burton Edward Ashley, Houston, Tex.
Louis A. Scholl, Jr., Elmer W. Ellsworth, John C. Miller
Chester Burns Claypool, Beaumont, Tex.
R. W. Pack, P. S. Justice, A. P. Allison
Glenn Edward Crays, Midland, Tex.
C. D. Cordry, B. E. Thompson, O. F. Hedrick
Fred A. Devin, Tulsa, Okla.
Joseph L. Borden, D. A. Green, Clyde M. Becker
Eugene Leonard Earl, Houston, Tex.
F. Julius Fohs, W. A. Reiter, David J. Crawford
Sam Charles Giesey, Midland, Tex.
A. L. Ackers, Addison Young, Ronald K. DeFord
Weldon Woolf Hammond, San Antonio, Tex.
Stuart Mossom, William W. Clawson, S. A. Thompson
J. Ed Heston, New York, N.Y.
L. C. Snider, E. P. Hindes, A. Ferd Morris
Robert Minssen Kleinpell, Bakersfield, Calif.
Richard R. Crandall, Thomas F. Stipp, R. D. Reed
Carl L. Larson, Jr., Wichita, Kan.
H. H. Kister, V. G. Hill, Jack M. Copass
Robinson Peale Lockwood, Great Bend, Kan.
W. B. Wilson, K. C. Heald, D. T. Ring

MID-YEAR MEETING, EL PASO, TEXAS SEPTEMBER 27–OCTOBER 2, 1938

The committee on arrangements for the mid-year meeting of the Association at El Paso, Texas, September 27–October 2, under the general chairmanship of Berte R. Haigh, of University Lands, Midland, is preparing for a large attendance of geologists and their friends. El Paso is midway between the Pacific Coast and the Mid-Continent and Gulf Coast oil fields, and near enough to the New Mexico and West Texas fields to bring them within the area of the field trips. Tentative plans for trips before and after the technical program include schedules into Chihuahua, Mexico, the Glass Mountains, Marathon uplift, Franklin Mountains, western New Mexico including the

vicinity of Silver City, the Carlsbad Caverns, and the West Texas and New Mexico oil fields. The chairman of the field trips committee is John Emery Adams, Standard Oil Company of Texas, Midland.

The technical sessions will be held September 29–30 at the Hotel Cortez, El Paso, headquarters of the convention. Ronald K. DeFord, Argo Oil Corporation, Midland, is chairman of the technical program committee.

Entertainment for wives of the members will probably include special receptions, luncheons, and a trip through the markets of Juarez, Mexico.

The meeting is being held in El Paso at the invitation and sponsorship of the West Texas Geological Society with the assistance of the El Paso chapter of the American Institute of Mining and Metallurgical Engineers, the New Mexico Geological Society, the South Texas Geological Society, San Antonio and Corpus Christi, the College of Mines and Metallurgy of the University of Texas, El Paso, and the New Mexico School of Mines, Socorro.

Technical program chairman DeFord has announced the following preliminary list of papers for the El Paso program.

1. Author?, "General Introduction to Regional Geography and Geology"
2. James Fitzgerald, Jr. (Skelly Oil Co., Midland, Tex.), William C. Fritz (Skelly Oil Co., Midland), E. Hazen Woods (Midland), Robert I. Dickey (Midland), "Cross Sections of Central Basin Platform"
3. Louis V. Olson (American Smelting and Refining Co., El Paso, Tex.), "Aerial Photography for Geological Exploration"
4. Cary P. Butcher (Tide Water Associated Oil Co., Midland, Tex.), "The Guadalupe Mountains as They Look to the Aerial Geologist"
5. Philip B. King (U. S. Geological Survey, Washington, D. C.), "Relation of Permian Sedimentation to Tectonics in Guadalupe Mountain Region"
6. George D. Riggs (Carlsbad, New Mexico), Ronald K. DeFord (Skelly Oil Co., Midland, Tex.), Neil H. Wills (Carlsbad, New Mex.), "Surface and Subsurface Formations, Eddy County, New Mexico"
7. George A. Kroenlein (Lovington, New Mex.), "Potash and Salt"
8. E. Russell Lloyd (Midland, Tex.), "Theory of Reef Barriers"
9. Frank E. Lewis (Midland, Tex.), "Stratigraphy of the Upper and Middle Permian of West Texas and Eastern New Mexico"
10. Lincoln R. Page, "Stratigraphy of Eastern Midland Basin, Texas"
11. Charles Taylor Cole (University Lands, Midland, Tex.), "Preliminary Notes on the Black Shale of West Texas"
12. John W. Skinner (Humble Oil and Refining Co., Midland, Tex.), "Upper Paleozoic of Chinati Mountains"
13. Author?, "Vacuum Field, Lea County, Texas"
14. Sam C. Giesy (Stanolind Oil and Gas Co., Midland, Tex.) and Frank Fulk, "North Cowden Field, Ector County, Texas"
15. H. M. Bayer (Midland, Tex.), "McElroy Field, Crane County, Texas"
16. M. G. Cheney (Coleman, Tex.), "North-Central Texas"
17. L. A. Nelson (College of Mines and Metallurgy, El Paso, Tex.), "Paleozoic Stratigraphy of the Franklin Mountains of West Texas"
18. Morris A. Elms (San Antonio, Tex.), "The Volcanics of the Buck Hills Quadrangle, Brewster County, Texas"

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

DONALD C. BARTON, *chairman*, Houston, Texas — H. B. FUQUA, Fort Worth, Texas
IRA H. CRAM, *secretary*, Tulsa, Oklahoma — HAROLD W. HOOTS, Los Angeles, California
W. A. VER WIEBE, Wichita, Kansas

BUSINESS COMMITTEE

CARL C. ANDERSON (1940)
ARTHUR A. BAKER (1940)
DONALD C. BARTON (1940)
WILLIAM A. BAKER (1939)
ORVAL L. BRACE (1939)
CARY P. BUTCHER (1939)
FREDERIC A. BUSH (1939)
HAROLD S. CAVE (1939)
ROBERT W. CLARK (1939)
IRA H. CRAM (1939)
A. F. CRIDER (1939)
A. ARTHUR CURTICE (1939)
H. B. FUQUA (1939)
BENJAMIN F. HAKE (1939)
V. G. HILL (1939)
HAROLD W. HOOTS (1939)
JOHN F. HOSTERMAN (1939)
H. V. HOWE (1939)
J. HARLAN JOHNSON (1939)
EDWARD A. KOESTER (1939)
P. W. MCFARLAND (1940)
DAVID PERRY OLCOTT (1939)
VIRGIL PETTIGREW (1940)
R. B. RUTLEDGE (1939)
R. F. SCHOOLFIELD (1939)
E. H. SELLARDS (1939)
FRED P. SHAVES (1939)
S. E. SLIPPER (1939)
HOMER J. STEINY (1939)
W. T. THOM, JR. (1939)
WALLACE C. THOMPSON (1940)
JAMES A. TONG (1939)
WALTER A. VER WIEBE (1939)
ANDREW C. WRIGHT (1939)

RESEARCH COMMITTEE

A. I. LEVORSEN (1941), *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma
HAROLD W. HOOTS (1939), *vice-chairman*, Richfield Oil Corporation, Los Angeles, California
M. G. CHENEY (1938), *vice-chairman*, Coleman, Texas

JOHN G. BARTRAM (1938)
C. E. DOBBIN (1938)
ROBERT H. DOTT (1938)
K. C. HEALD (1938)
STANLEY C. HEROLD (1938)
F. H. LAHEE (1938)
H. A. LEY (1938)
THEODORE A. LINK (1938)
C. V. MILLIKAN (1938)
R. C. MOORE (1938)
F. B. PLUMMER (1938)
JOHN L. RICH (1938)
C. W. TOMLINSON (1938)
GLENN H. BOWES (1939)
W. L. GOLDSTON (1939)
W. C. SPOONER (1939)
PARKER D. TRASK (1939)
MAURICE M. ALBERTSON (1940)
WILLIAM E. HUBBARD (1940)
JOHN C. KARCHER (1940)
NORMAN L. THOMAS (1940)

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

FREDERIC H. LAHEE (1940)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

JOHN G. BARTRAM, *chairman*, Stanolind Oil and Gas Company, Casper, Wyoming

M. G. CHENEY
ALEXANDER DEUSSEN
GLENN S. DILLE
B. F. HAKE
G. D. HANNA
M. C. ISRAELSKY
A. I. LEVORSEN
C. L. MOODY
R. C. MOORE
ED. W. OWEN
J. R. REEVES
ALLEN C. TESTER
W. A. THOMAS

TRUSTEES OF REVOLVING PUBLICATION FUND

J. V. HOWELL (1939) — RALPH D. REED (1940) — BEN F. HAKE (1941)

TRUSTEES OF RESEARCH FUND

ALEX W. MCCOY (1939) — ROBERT J. RIGGS (1940) — A. A. BAKER (1941)

FINANCE COMMITTEE

W. B. HEROY (1939) — E. DEGOLYER (1940) — WALLACE E. PRATT (1941)

COMMITTEE ON APPLICATIONS OF GEOLOGY

FRANK RINKER CLARK, *chairman*, Box 981, Tulsa, Oklahoma

OLIN G. BELL
ARTHUR E. BRAINERD
IRA OTHO BROWN
HAL P. BYBEE
CAREY CRONEIS
ROBERT H. DOTT
H. S. MCQUEEN
S. E. SLIPPER
E. K. SOPER
EARL A. TRAGER

COMMITTEE FOR PUBLICATION

FREDERIC H. LAHEE, *chairman*, Box 2880, Dallas, Texas

CARL C. ANDERSON
WALTER R. BERGER
CHARLES BREWER, JR.
T. C. CRAIG
GEORGE R. DOWNS
JAMES TERRY DUCE
JAMES FITZGERALD, JR.
HAROLD W. HOOTS
J. HARLAN JOHNSON
EDWARD A. KOESTER
CHAS. H. LAVINGTON
A. I. LEVORSEN
A. M. LLOYD
W. A. MALEY
PHILLIP F. MARTYN
GRAHAM B. MOODY
ED. W. OWEN
R. E. RETTGER
J. T. RICHARDS
THERON WASSON
A. W. WEEKS
A. C. WRIGHT

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 7 (JULY, 1938), PP. 946-952

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

W. B. WEEKS, Phillips Petroleum Corporation, El Dorado, Arkansas, recently spoke before the Dallas Geological Society on the subject, "Stratigraphy of Southern Arkansas in the Light of Deeper Drilling."

R. C. BOWLES, Houston, has recently been elected to the office of vice-president of the Standard Oil Company of Kansas.

LÉONCE JOLEAUD, professor of geology and paleontology at Sorbonne University, died April 15.

B. W. BEEBE has accepted the position of district geologist for The British American Oil Producing Company at Wichita, Kansas, effective June 1. BEEBE recently resigned as geologist in the office of the vice-president of exploration of the Shell Petroleum Corporation, St. Louis, Missouri.

FRANK A. MORGAN, Los Angeles, has been elected a vice-president of the Richfield Oil Corporation.

GORDON W. HEID, Shell Petroleum Corporation, Midland, spoke before the West Texas Geological Society, June 1, about the Dutch East Indies.

LEWIS B. KELLUM, associate professor of geology at the University of Michigan, will direct the geological exploration of the Standard Oil group and associates in New Zealand. He has been granted leave of absence from the University next year. He sailed to New Zealand last month. His address is in care of the Vacuum Oil Co. Pty., Ltd., Wellington, New Zealand.

EVERETT A. WYMAN, Amerada Petroleum Corporation, Tulsa, and Maude McMorris, Tulsa, were married recently in San Antonio.

ALFRED P. FREY left Maracaibo, Venezuela, early in June, and may be addressed at Sonneggstrasse 48, Zurich, Switzerland.

The Kansas Geological Society visited the mine of the Carey Salt Company at Hutchinson, Kansas, April 16.

CECIL DRAKE has changed his address from Tampico, Mexico, to Lyons, Kansas.

JOHN M. VETTER, Pan American Production Company, Houston, has been appointed supervisor of the land and geological department.

ROBERT WESLEY BROWN, St. Lawrence University, Canton, New York, was elected president of the New York State Geological Association at the fourteenth annual meeting in Buffalo, May 13–14.

H. KLAUS, president of the Klaus Exploration Company, announces the opening of an office in the Benson Building, Lubbock, Texas, in addition to the company's office in the Broadway Tower, Enid, Oklahoma.

JAMES K. MURPHY, recently with the Home Stake Companies, has accepted the position of chief geologist for the British American Cil Producing Company, Tulsa.

J. S. HEROLD, formerly with the Cities Service Oil Company, is now with the Shell Petroleum Corporation at Midland, Texas.

G. J. SMITH, Pan American Production Company, Houston, has been appointed assistant superintendent of the geological department.

C. H. SAMPLE, Houston Oil Company, Houston, spoke before the Houston Geological Society, May 26, on "Geology of the Lucas Field, Live Oak County, Texas."

M. R. WILSON, formerly with Duncan Brothers at Flora, Illinois, is now working in Mississippi for the Ohio Oil Company.

M. G. KELSEY is head of a survey party of 17 men who are doing geophysical work in Alberta, Canada, for American companies. Headquarters for the party are in Medicine Hat, Southern Alberta.

E. H. WALKER, formerly geologist for Phelps-Dodge Copper Company, Bisbee, Arizona, has accepted a position with Shell Petroleum Corporation at Midland, Texas.

O. E. BROWN, Salt Dome Oil Corporation, Houston, has been transferred to Corpus Christi, Texas, where he is scout in the lower Gulf Coast district.

The annual meeting of the Pacific Coast section of the Society of Economic Paleontologists and Mineralogists was held at Paso Robles, California, June 3–4. R. D. REED, The Texas Company of California, led a discussion on the geologic problems of the Salinas valley.

M. G. CHENEY, Coleman, Texas, was recently elected president of the newly formed Maxwell Drilling Company of Coleman.

M. M. LEIGHTON, Urbana, Illinois, led a field conference for oil geologists, June 25–26, in southeast Illinois. The conference started from Harrisburg, June 25, and returned that evening for a banquet.

A grant in aid from the permanent science fund of the American Academy of Arts and Science to CHARLES T. BERRY, Johns Hopkins University, of $247 toward expenses of collecting fossil ophiurans in a micropaleontological problem of stratigraphy, was announced at the meeting of the committee April 13.

RUSSELL GIBSON, IAN CAMPBELL, and W. F. JENKS are the authors of "Quartz Monzonite and Related Rocks of the Libby Quadrangle, Montana, and the Effects on Them of Deuteric Processes," which was published in the May number of the *American Journal of Science.*

J. F. HOSTERMAN and LARRY MEISTER, Amerada Petroleum Corporation, have been transferred from Fort Worth to Tulsa, to complete the centralization of the company in Tulsa.

T. K. KNOX, Republic Natural Gas Company, has changed his address from Corpus Christi to 1505 Federal Street, Dallas, Texas.

GEORGE W. LAPEIRE, consulting geologist, has moved his office from Robinson, Illinois, to San Antonio, Texas.

M. H. STEIG, Phillips Petroleum Corporation, has been appointed district geologist in the company's new offices in Houston, Texas.

D. H. BINGHAM, Phillips Petroleum Corporation, has been transferred from Shreveport to Lafayette, Louisiana, where he will be district geologist.

G. S. HUME, of the Dominion Geological Survey, recently addressed a meeting of the Manitoba section of the Canadian Institute of Mining and Metallurgy, at Winnipeg, on the Turner Valley field.

ALEXANDER DEUSSEN and KENNETH DALE OWEN spoke before the Houston Geological Society, June 9, on the subject, "Correlation of Surface and Subsurface Formations in Two Typical Sections of the Gulf Coast."

S. E. Slipper, chief geologist of the Canadian Western Natural Gas, Light, Heat, and Power Company, Ltd., Calgary, Alberta, has recently been elected a Fellow of the Royal Society of Canada.

GORDON H. WHITE, Shell Petroleum Corporation, has been transferred from San Antonio to Houston, Texas, where he may be addressed in care of the exploration department.

W. E. GREENMAN, The Texas Company, Houston, spoke before the Houston Geological Society at the weekly luncheon, June 16. His subject was "Geology of Picket Ridge Oil Field, Wharton County."

PAUL H. PRICE, West Virginia State geologist, has been appointed professor and head of the department of geology of West Virginia University.

JOHN C. MILLER, The Texas Company, spoke before the South Texas Geological Society at Corpus Christi, June 17, on "Tertiary Formations of Texas Gulf Coast."

The Geological Society of America has awarded a grant from the Penrose bequest to PERRY BYERLY, professor of seismology at the University of California, to study the vibration of the earth's crust during earthquakes.

JOSEPH PURZER has been named district chief geologist in Shreveport for the Phillips Petroleum Company. He succeeds D. H. BINGHAM who has been transferred to Lafayette, Louisiana.

The Shawnee (Oklahoma) Geological Society held a one-day field trip over the Thurman, Boggy, Savanna, McAlester, and Hartshorne formations on June 18. T. A. HENDRICKS, who has spent several years mapping and studying the formations in the McAlester area for the United States Geological Survey, was the leader. This field trip was the second of a series planned by the Society. The third trip, to be held next fall, will cover beds from the Calvin to the Thurman. The fourth trip, also planned for next fall, is to cover beds of the Atoka formation. The purpose of this series of conferences is to study the Pennsylvanian beds of the area at their outcrops to correlate the surface and subsurface sections to fit the sections into the standard Pennsylvanian nomenclature as developed on the north.

F. MABRY HOOVER, of the Cities Service Oil Company, spoke recently on "The Stratigraphy of Southern Oklahoma," at the technical session of the Oklahoma City Geological Society. The Society's annual picnic was held, June 25–26, at Sulphur.

ROBERT L. JONES, geologist with the Cities Service Oil Company, has been transferred from Tyler to the Houston office of the company.

The American Institute of Mining and Metallurgical Engineers has scheduled the following fall meetings.

Petroleum Division, A.I.M.E., fall meeting, San Antonio, Texas, October 6–7.

Industrial Minerals Division, A.I.M.E., meeting jointly with the Society of Economic Geologists at Knoxville, Tennessee, October 6–8.

Coal Division, A.I.M.E., Fuel Division, American Society of Mechanical Engineers, and Western Society of Engineers, meeting jointly at Palmer House, Chicago, October 13–15.

Institute of Metals and Iron and Steel Divisions, A.I.M.E., fall meetings in conjunction with National Metal Congress, Book-Cadillac Hotel, Detroit, October 17–20.

Industrial Minerals Division and Petroleum Division, A.I.M.E., Los Angeles, October 20–21.

A.I.M.E., Regional Meeting, Tucson, Arizona, November 1–5.

At a recent meeting of the Panhandle Geological Society the following officers were elected for the ensuing year. B. L. PILCHER, The Texas Company, president; W. D. HENDERSON, Stanolind Oil and Gas Company, vice-president; G. R. CARTER, Gulf Oil Corporation, secretary and treasurer; C. C. ANDERSON, United States Bureau of Mines, district representative.

O. E. Walton, formerly of Corpus Christi, Texas, may now be addressed in care of The Atlantic Refining Company, Magnolia Building, Dallas, Texas.

Roland M. Harper, Alabama Geological Survey, led a geological field trip for the Alabama Academy of Science during the annual meeting of the Academy held at State Teachers College at Troy, April 8–9.

FANNY CARTER EDSON has resigned from The Shell Petroleum Corporation, and may be addressed at 3145 South Rockford Drive, Tulsa, Oklahoma.

BRUCE WHITCOMB, who has been with The Texas Company at Bogota, Colombia, may now be addressed at Box 106, Groesbeck, Texas.

HARRY W. OBORNE, consulting geologist of Colorado Springs, Colorado, will act as director of the Twelfth Annual Field Conference of the Kansas Geological Society in coöperation with the Rocky Mountain Association of Petroleum Geologists, September 1–3. He will be assisted by C. E. DOBBIN of the United States Geological Survey, Denver, Colorado, ROSS L. HEATON of the Bureau of Reclamation, Denver, Colorado, and A. E. BRAINERD of the Continental Oil Company, Denver, Colorado. These men are well acquainted with the geology of the Rocky Mountain Front Range and their leadership will be a great help, assuring a successful field trip. The Conference will convene at La Junta, Colorado, and travel southwest across the Apishapa

uplift to Walsenburg. Thence northwesterly it will proceed through Rye and Beulah to Cañon City. The northwest extension of the Apishapa uplift and the overlap of the Dakota sandstone on the pre-Cambrian near Rye and excellent pre-Pennsylvanian sections at Beulah and Cañon City will be observed.

On the second day the route will be northward from Cañon City to Colorado Springs. The type locality of the Fountain sandstone and Glen Eyrie shales (Cherokee) will be visited at Colorado Springs, where an interesting pre-Pennsylvanian section will also be studied. A section from the pre-Cambrian to the Pierre shale will be inspected in a distance of about 1½ miles. From Colorado Springs the Conference continues northward through Perry Park to Boulder. *En route* the most northerly extension of pre-Pennsylvanian rocks known in Colorado and an oil seep in fractured pre-Cambrian rocks north of Golden will be observed.

The third day the Conference will continue northward from Boulder to the Wyoming line, visiting the type locality of the Lyons sandstone and the fossiliferous Ingelside formation of Upper Pennsylvanian age. An exposure of Pennsylvanian basal conglomerate composed of Mississippian boulders will also be seen. From Beulah northward to this area the unconformity at the base of the Pennsylvanian should be of particular interest to those geologists familiar with the Pennsylvanian basal conglomerates of the Central Kansas uplift. The geology of the Big Thompson Canyon—Grand Lake area will be discussed by ROSS L. HEATON, geologist for the Bureau of Reclamation, and MARGARET FULLER BOOS of Denver University. The party will then return to Estes Park where a dance and social entertainment are planned for Saturday night. A registration fee, not exceeding $8.00, will be charged to help defray the expenses of the conference. This will include the price of the guide book. Extra guide books may be purchased for not more than $5.00 each. Further information may be obtained from the Kansas Geological Society, 412 Union National Bank Building, Wichita, Kansas.

The officers, executive committee, and members of the Division of Geology and Geography of the National Research Council, for the year beginning July 1, are as follows: chairman, CHESTER R. LONGWELL; vice-chairman, PRESTON E. JAMES; executive committee, CHESTER R. LONGWELL, PRESTON E. JAMES, NORMAN L. BOWEN, F. H. LAHEE, JOHN L. RICH, JOHN K. WRIGHT; representative of societies, STEPHEN R. CAPPS and JOHN L. RICH, Geological Society of America; J. F. SCHAIRER, Mineralogical Society of America; CHARLES E. RESSER, Paleontological Society; PRESTON E. JAMES and C. WARREN THORNTHWAITE, Association of American Geographers; JOHN K. WRIGHT, American Geographical Society; EDSON S. BASTIN, Society of Economic Geologists; ROBERT B. SOSMAN, American Ceramic Society; F. H. LAHEE, American Association of Petroleum Geologists; members at large, NORMAN L. BOWEN, CHESTER R. LONGWELL and L. F. THOMAS.

FRITZ L. AURIN has recently been made president of the Southland Royalty Company, Fort Worth.

MARVIN LEE, Wichita, Kansas, is in Cuba making a preliminary geological survey regarding oil and gas possibilities of the island.

C. H. BEHRE, JR., has returned to Northwestern University after a year's

leave of absence, spent in studying the origin of lead and zinc deposits in Europe and northern Africa under a Guggenheim Fellowship.

HENRY SALVATORI, president of the Western Geophysical Company, has moved his offices to 711 Edison Building, Los Angeles, California.

FRANK S. WESTMORELAND, formerly with the Shell Petroleum Corporation, is now practicing consulting geology and paleontology at 2311 Dunston Road, Houston, Texas.

R. J. GONZALES, Humble Oil and Refining Company, Houston, spoke before the Houston Geological Society, June 30, on "The Economic Conservation of Oil Resources."

ROBERT G. COUCH has changed his address from Rush Springs, Wyoming, to the United Geophysical Company, 168 North Hill Avenue, Pasadena, California.

L. G. KEPPLER, formerly with the Lewis Production Company, Dallas, is now with the Montour Production Company, 210 Guardian Life Building, Dallas, Texas.

A. E. FATH may now be addressed in care of the Socony-Vacuum Oil Company, Benoordenhout 7, The Hague, Netherlands.

M. A. DRESSER, The Carter Oil Company, has been transferred from Denver, Colorado, to Tulsa, Oklahoma.

The Geological Society of America has made grants for nineteen research projects as follows.

LOUIS B. SLICHTER, professor of geophysics, Massachusetts Institute of Technology, $5,350 for a large-scale seismic investigation of the earth's crust in New England.

PERRY BYERLY, professor of seismology, University of California, $900 for an investigation to determine whether various portions of the earth's crust have free vibration periods during earthquakes.

DAVID GRIGGS, research physicist, Harvard University, $675 for constructing instruments to test the deformation of rocks under high confining pressures in the laboratory.

HARRY J. KLEPSER, instructor in geology, Capital University, Columbus, Ohio, $300 to complete a detailed stratigraphic study of rock formations of Lower Mississippian age in the Highland Rim of central Tennessee.

HAROLD R. WANLESS, associate professor of geology, University of Illinois, $1,542 for field studies of rock formation of Pennsylvanian age in Kentucky, Tennessee, Alabama and possibly Virginia.

CLAUDE C. ALBRITTON, Southern Methodist University, and KIRK BRYAN, Harvard University, $500 for an investigation of Ice Age deposits near Alpine, Texas, containing human remains and fossils of extinct animals.

ERNST CLOOS, associate professor of geology, Johns Hopkins University,

$900 for a study of the age of the Glenarm rock series in Pennsylvania and Maryland, which has long been in dispute.

CHARLES S. DENNY, instructor in geology, Harvard University, $355 for a study of the Santa Fe formation of Tertiary age, in the region north of Santa Fe, New Mexico.

MAX DEMOREST, fellow in the Graduate School of Princeton University, $400 for the detailed study of an area extending across the Bighorn Mountains of Wyoming from Bighorn in the east to Shell Creek Canyon on the west.

FRED B. PHLEGER, JR., instructor in geology, Amherst College, $500 for a study of microscopic animal life in submarine cores, recently taken from the North Atlantic Ocean.

KENNETH E. CASTER, curator of the Museum of Paleontology of the University of Cincinnati, $500 to restudy and illustrate North American pelecypods of the Devonian.

EDWARD B. MATHEWS, professor of geology, Johns Hopkins University, $700 to continue his work in collecting analyses of all igneous rock from North America and elsewhere.

R. W. IMLAY, research associate, Museum of Paleontology of the University of Michigan, $835 for field studies of stratigraphy and paleontology and studies of connections between the Atlantic and Pacific across northern Sonora, Mexico, that existed during the Mesozoic era.

GILBERT D. HARRIS, professor of paleontology, Cornell University, and KATHERINE VAN WINKLE PALMER, of the Paleontological Research Institution, Ithaca, N. Y., $700 for a field and laboratory study to complete a series of monographs on the mollusks of the Eocene formations of the southeastern states.

CHARLES DEISS, professor of geology, Montana State University, $400 to continue studies leading to the revision of the Cambrian rock formations in the Canadian Rockies and the northeastern states.

CHARLES F. BASSETT, assistant professor of geology, University of Kansas City, $300 to collect fossils and to study a section of Paleozoic rocks near Dotsero, Colorado.

RICHARD FOSTER FLINT, professor of geology, Yale University, $365 for an examination and interpretation of the glacial deposits in Columbia River Canyon, exposed during the construction of Coulée Dam.

J. HOOVER MACKIN, assistant professor of geology, University of Washington, $260 for a revision of the glacial geology of the Puget-Juan de Fuca region of Washington.

ARTHUR KEITH, U. S. Geological Survey, Washington, D. C., $665 to continue and complete his studies of Appalachian structure and stratigraphy in the Province of Quebec and adjacent areas.

PROFESSIONAL DIRECTORY

Space for Professional Cards Is Reserved for Members of the Association. For Rates Apply to A.A.P.G. Headquarters, Box 979, Tulsa, Oklahoma

CALIFORNIA

WILLARD J. CLASSEN
Consulting Geologist
Petroleum Engineer
1093 Mills Building
SAN FRANCISCO, CALIFORNIA

RICHARD R. CRANDALL
Consulting Geologist
404 Haas Building
LOS ANGELES, CALIFORNIA

J. E. EATON
Consulting Geologist
2062 N. Sycamore Avenue
LOS ANGELES, CALIFORNIA

PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
799 Subway Terminal Building
LOS ANGELES, CALIFORNIA

C. R. McCOLLOM
Consulting Geologist
Richfield Building
LOS ANGELES, CALIFORNIA

WALTER STALDER
Petroleum Geologist
925 Crocker Building
SAN FRANCISCO, CALIFORNIA

IRVINE E. STEWART
Consulting Geologist
Suite 505
811 West Seventh Street Building
LOS ANGELES, CALIFORNIA

JACK M. SICKLER
Geologist
Pacific Mutual Building
LOS ANGELES, CALIFORNIA

VERNON L. KING
Petroleum Geologist and Engineer
1227 Bank of America Building
LOS ANGELES, CALIFORNIA

R. W. SHERMAN
Consulting Geologist
Pacific Mutual Building
523 West Sixth St.
LOS ANGELES

CALIFORNIA

R. L. TRIPLETT
Contract Core Drilling

WHitney 9876 — 2013 West View St. Los ANGELES, CALIF.

CHAS. GILL MORGAN

United Geophysical Company
Pasadena — California

COLORADO

HEILAND RESEARCH CORPORATION
Registered Geophysical Engineers

— *Instruments* —
— Surveys — Interpretations —

C. A. HEILAND, *President* — Club Bldg. DENVER, COLO.

JOHN H. WILSON
Geologist and Geophysicist

Colorado Geophysical Corporation
610 Midland Savings Building, DENVER, COLORADO

CUBA

R. H. PALMER
Petroleum Geologist

Examinations and Reports on
Cuban Oil Lands

Neptuno 234 — HABANA, CUBA

KANSAS

R. B. (IKE) DOWNING
Geological Engineer

Pipe setting—Drilling in—Sample determinations
Surface and Subsurface Geology
Magnetic Surveys

Union National Bank Bldg., WICHITA, KANSAS

L. C. MORGAN
Petroleum Engineer and Geologist

Specializing in Acid-Treating Problems

358 North Dellrose
WICHITA, KANSAS

MARVIN LEE
Consulting Petroleum Geologist
1109 Bitting Building
WICHITA, KANSAS

Office: 3-8941 — *Residence: 4-4873*

GEOLOGY AND PRODUCTION PROBLEMS OF OIL AND GAS IN THE UNITED STATES

Formerly Technical Adviser to State Corporation Commission. Official mail should be addressed to the Commission.

HOLL AND OBORNE
Consulting Geologists

F. G. HOLL, 4121 East English, Wichita, Kansas
HARRY W. OBORNE, 1328 North Tejon St., Colorado Springs, Colo.

LOUISIANA

WILLIAM M. BARRET, INC.
Consulting Geophysicists

Specializing in Magnetic Surveys

Giddens-Lane Building — SHREVEPORT, LA.

NEW MEXICO

RONALD K. DEFORD
Geologist

ROSWELL, NEW MEXICO — MIDLAND, TEXAS

NEW YORK

FREDERICK G. CLAPP
Consulting Geologist
50 Church Street
NEW YORK

BROKAW, DIXON & McKEE
Geologists *Engineers*
OIL—NATURAL GAS
Examinations, Reports, Appraisals
Estimates of Reserves
120 Broadway, New York
Gulf Building, Houston

A. H. GARNER
Geologist *Engineer*
PETROLEUM
NATURAL GAS
120 Broadway New York, N.Y.

OHIO

JOHN L. RICH
Geologist
Specializing in extension of "shoestring" pools
University of Cincinnati
Cincinnati, Ohio

OKLAHOMA

ELFRED BECK
Geologist
525 National Bank of Tulsa Building
TULSA OKLAHOMA

GINTER LABORATORY
CORE ANALYSES
Permeability
Porosity
Reserves
R. L. GINTER
Owner
118 West Cameron, Tulsa

MALVIN G. HOFFMAN
Geologist
Midco Oil Corporation
Midco Building
TULSA, OKLAHOMA

R. W. Laughlin L. D. Simmons
WELL ELEVATIONS
Oklahoma, Kansas, Texas, and
New Mexico
LAUGHLIN-SIMMONS & CO.
605 Oklahoma Gas Building
TULSA OKLAHOMA

MID-CONTINENT TORSION BALANCE SURVEYS
SEISMIC AND GRAVITY INTERPRETATIONS
KLAUS EXPLORATION COMPANY
H. KLAUS
Geologist and Geophysicist
Broadway Tower, Enid, Okla.
Benson Building, Lubbock, Texas

A. I. LEVORSEN
Petroleum Geologist
221 Woodward Boulevard
TULSA OKLAHOMA

OKLAHOMA

GEO. C. MATSON
Geologist
Philcade Building — TULSA, OKLA.

G. H. WESTBY
Geologist and Geophysicist
Seismograph Service Corporation
Kennedy Building — Tulsa, Oklahoma

U. R. LAVES
(BILL LAVES)
Geologist
Pipe setting—Sample determination—Reports
723 S. Broadway — ADA, OKLAHOMA

PENNSYLVANIA

HUNTLEY & HUNTLEY
Petroleum Geologists and Engineers
L. G. HUNTLEY
J. R. WYLIE, JR.
H. RUTHERFORD, *Geophysics*
Grant Building, Pittsburgh, Pa.

TEXAS

JOSEPH L. ADLER
Geologist and Geophysicist
Consultant and Contractor in Geological and Geophysical Exploration
325 Esperson Bldg.
HOUSTON, TEXAS

MID-CONTINENT TORSION BALANCE SURVEYS
SEISMIC AND GRAVITY INTERPRETATIONS
KLAUS EXPLORATION COMPANY
H. KLAUS
Geologist and Geophysicist
Broadway Tower, Enid, Okla. — Benson Building, Lubbock, Texas

DONALD C. BARTON
Geologist and Geophysicist
Humble Oil and Refining Company
HOUSTON — TEXAS

D'ARCY M. CASHIN
Geologist — *Engineer*
Specialist, Gulf Coast Salt Domes
Examinations, Reports, Appraisals
Estimates of Reserves
705 Nat'l. Standard Bldg.
HOUSTON, TEXAS

E. DEGOLYER
Geologist
Esperson Building
Houston, Texas
Continental Building
Dallas, Texas

ALEXANDER DEUSSEN
Consulting Geologist
Specialist, Gulf Coast Salt Domes
1006 Shell Building
HOUSTON, TEXAS

DAVID DONOGHUE
Consulting Geologist
Appraisals - Evidence - Statistics
Forth Worth National Bank Building — FORT WORTH, TEXAS

F. B. Porter, *President* — R. H. Fash, *Vice-President*
THE FORT WORTH LABORATORIES
Analyses of Brines, Gas, Minerals, Oil, Interpretation of Water Analyses. Field Gas Testing.
828½ Monroe Street — FORT WORTH, TEXAS
Long Distance 138

TEXAS

J. S. HUDNALL G. W. PIRTLE

HUDNALL & PIRTLE

Petroleum Geologists

Appraisals Reports

Peoples Nat'l. Bank Bldg. TYLER, TEXAS

JOHN S. IVY

Geologist

921 Rusk Building, HOUSTON, TEXAS

W. P. JENNY

Geologist and Geophysicist

Gravimetric Seismic
Magnetic Electric

Surveys and Interpretations

2102 Bissonett HOUSTON, TEXAS

PHILLIP MAVERICK

Petroleum Geologist

Western Reserve Life Building

SAN ANGELO TEXAS

DABNEY E. PETTY

315 Sixth Street

SAN ANTONIO, TEXAS

No Commercial Work Undertaken

E. E. ROSAIRE

SUBTERREX

BY

Geophysics and Geochemistry

Esperson Building Houston, Texas

A. T. SCHWENNESEN

Geologist

1517 Shell Building

HOUSTON TEXAS

ROBERT H. DURWARD

Geologist

Specializing in use of the magnetometer and its interpretations

1431 W. Rosewood Ave. San Antonio, Texas

W. G. SAVILLE J. P. SCHUMACHER A. C. PAGAN

TORSION BALANCE EXPLORATION CO.

Torsion Balance Surveys

1404-10 Shell Bldg. Phone: Capitol 1341
HOUSTON TEXAS

HAROLD VANCE

Petroleum Engineer

Petroleum Engineering Department
A. & M. College of Texas
COLLEGE STATION, TEXAS

WYOMING

E. W. KRAMPERT

Geologist

P.O. Box 1106
CASPER, WYOMING

WM. C. McGLOTHLIN

Petroleum Geologist and Engineer

Examinations, Reports, Appraisals
Estimates of Reserves

Geophysical Explorations

806 State Nat'l. Bank Bldg., CORSICANA, TEXAS

DIRECTORY OF GEOLOGICAL AND GEOPHYSICAL SOCIETIES

For Space Apply to A.A.P.G. Headquarters
Box 979, Tulsa, Oklahoma

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - Charles S. Lavington
Continental Oil Company
1st Vice-President - - Warren O. Thompson
985 Gilbert Street, Boulder
2nd Vice-President - - - David B. Miller
1336 Gaylord Street
Secretary-Treasurer - - - - - - Ninetta Davis
224 U. S. Customs Building

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - Edward A. Koester
Darby Petroleum Corporation
Vice-President - - - - Glen C. Woolley
Transwestern Oil Company
Secretary-Treasurer - - Forrest E. Wimbish
517 North Chautauqua
Member of Board - - - - - - George H. Norton
Atlantic Refining Company

Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.
The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - B. W. Blanpied
Gulf Oil Corporation
Vice-President - - - - - - E. B. Hutson
Standard Oil Company of Louisiana
Secretary-Treasurer - - - - J. D. Aimer
Arkansas-Louisiana Gas Company

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - J. F. Mahoney
Union Sulphur Co., Sulphur Mines, La.
Vice-President - - - - - - - - Dean F. Metts
Humble Oil & Refining Co., Crowley, La.
Secretary - - - - - - - - - W. R. Canada
Stanolind Oil and Gas Company
Treasurer - - - - - - - - Baker Hoskins
Shell Petroleum Corporation

Meetings: First Monday at noon (12:00) and third Monday at 7:00 P.M. at Majestic Hotel. Visiting geologists are welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - Jerome M. Westheimer
Consulting Geologist
Vice-President - - - - - - - - O. H. Hill
Shell Petroleum Corporation
Secretary-Treasurer - - - - - - - - J. P. Gill
Sinclair Prairie Oil Company
Chairman Program Committee - - Don L. Hyatt
Carter Oil Company, Dillard, Oklahoma

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - E. A. Paschal
Coline Oil Company
Vice-President - - - - Dan O. Howard
Oklahoma Corporation Commission
Secretary-Treasurer - - - - - R. B. Curry
Carter Oil Company, 420 Colcord Building

Meetings: Second Monday, each month, 8:00 P.M., Magnolia Building. Luncheons: Every Monday, 12:15 P.M., Ninth Floor, Commerce Exchange Building.

OKLAHOMA

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - A. M. Meyer
Atlantic Refining Company

Vice-President - - - - - - - - V. G. Hill
Stanolind Oil and Gas Company

Secretary-Treasurer - - - J. Lawrence Muir
Amerada Petroleum Corporation

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

THE STRATIGRAPHIC SOCIETY OF TULSA
TULSA, OKLAHOMA

President - - - - - - - - - - L. H. Lukert
The Texas Company

Vice-President - - - - - - - L. A. Johnston
Sunray Oil Company

Secretary-Treasurer - - Constance Leatherock
Tide Water Associated Oil Company

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - Robert J. Riggs
Stanolind Oil and Gas Company

1st Vice-President - - - - - - - N. W. Bass
United States Geological Survey

2nd Vice-President - - - - - Clark Millison
McBirney Building

Secretary-Treasurer - - - - - L. A. Johnston
Sunray Oil Company

Editor - - - - - - - - R. V. Hollingsworth
Shell Petroleum Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., fourth floor, Tulsa Building. Luncheons: Every Thursday, fourth floor, Tulsa Building.

TEXAS

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - Dilworth S. Hager
932 Liberty Building

Vice-President - - - - - - - R. E. Rettger
Sun Oil Company

Secretary-Treasurer - - - W. W. Clawson
Magnolia Petroleum Company

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - Robert L. Jones
Cities Service Oil Company

Vice-President - - - - - - - - A. C. Wright
Shell Petroleum Corporation

Secretary-Treasurer - - - - - - C. L. Herold
Shell Petroleum Corporation

Meetings: Monthly and by call.

Luncheons: Every Friday, Cameron's Cafeteria.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - A. L. Ackers
Stanolind Oil and Gas Company

Vice-President - - - - Clarence E. Hyde
1715 W. T. Waggoner Building

Secretary-Treasurer - - Herbert H. Bradfield
The Texas Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - John C. Miller
The Texas Company

Vice-President - - - - David Perry Olcott
Humble Oil and Refining Company

Secretary-Treasurer - - Lon D. Cartwright, Jr.
Skelly Oil Company

Regular meetings, every Thursday at noon (12:15) at the Houston Club. Frequent special meetings called by the executive committee. For any particulars pertaining to meetings call the secretary.

TEXAS

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - - - A. W. Weeks
Box 82

Vice-President - - - - - - Tom F. Petty
Humble Oil & Refining Company

Secretary-Treasurer - - - Paul E. M. Putcell
Shell Petroleum Corporation

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY

SAN ANTONIO AND CORPUS CHRISTI TEXAS

President - - - - - - - - W. A. Maley
Humble Oil and Refining Company, Corpus Christi

Vice-President - - - - - - W. W. McDonald
Arkansas Natural Gas Company, San Antonio

Secretary-Treasurer - - - - - - C. C. Miller
The Texas Company, Corpus Christi

Executive Committee - - - - - D. G. Barnett

Meetings: Third Friday of each month at 8 P.M. at the Petroleum Club. Luncheons every Monday noon at Petroleum Club, Alamo National Building, San Antonio, and at Plaza Hotel, Corpus Christi.

WEST TEXAS GEOLOGICAL SOCIETY

SAN ANGELO AND MIDLAND, TEXAS

President - - - - - - - - H. A. Hemphill
Magnolia Petroleum Company, Midland

Vice-President - - - - - - W. D. Anderson
Amerada Petroleum Corporation, Midland

Secretary-Treasurer - - - - - - - W. C. Fritz
Skelly Oil Company, Midland

Meetings will be announced

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - F. M. Kannenstine
Kannenstine Laboratories, Houston, Texas
2011 Esperson Building

Vice-President - - - - - - - - W. T. Born
Geophysical Research Corporation
Tulsa, Oklahoma

Editor - - - - - - - M. M. Slotnick
Humble Oil & Refining Co., Houston, Texas

Secretary-Treasurer - - - - - - H. B. Peacock
Geophysical Service, Inc., Houston, Texas
825 Esperson Building

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA
P.O. Box 1435

President - - - - - Robert C. Lafferty
Owens, Libbey-Owens Gas Department

Vice-President - - - J. Hawker Newlon
Philadelphia Gas Company
Pittsburgh, Pennsylvania

Secretary-Treasurer - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 348

Meetings: Second Monday, each month, at 6:30 P.M., Kanawha Hotel.

TRIANGLE BLUE PRINT & SUPPLY COMPANY

Representing
W. & L. E. Gurley
Spencer Lens American Paulin

Complete Reproduction Plant
Instruments Repaired

12 West Fourth Street, Tulsa, Oklahoma

RESERVED FOR

ILLINOIS POWDER MANUFACTURING COMPANY

REVUE DE GÉOLOGIE
et des Sciences connexes

REVIEW OF GEOLOGY
and Connected Sciences

RASSEGNA DI GEOLOGIA
e delle Scienze affini

RUNDSCHAU FÜR GEOLOGIE
und verwandte Wissenschaften

Abstract journal published monthly with the coöperation of the FONDATION UNIVERSITAIRE DE BELGIQUE and under the auspices of the SOCIÉTÉ GEOLOGIQUE DE BELGIQUE with the collaboration of several scientific institutions, geological surveys, and correspondents in all countries of the world.

GENERAL OFFICE, *Revue de Géologie*, Institut de Géologie, Université de Liége, Belgium.

TREASURER, *Revue de Géologie*, 35, Rue de Armuriers, Liége, Belgium.

Subscription, Vol. XVIII (1938), 35 belgas *Sample Copy Sent on Request*

The Annotated

Bibliography of Economic Geology
Vol. X, No. 1

Is Now Ready

Orders are now being taken for the entire volume at $5.00 or for individual numbers at $3.00 each. Volumes I-IX can still be obtained at $5.00 each.

The number of entries in Vol. I is 1,756. Vol. II contains 2,480, Vol. III, 2,260, Vol. IV, 2,224, Vol. V, 2,225, Vol. VI, 2,085, Vol. VII, 2,166, and Vol. VIII, 1,186.

Of these 4,670 refer to *petroleum, gas,* etc., and *geophysics.* They cover the world.

If you wish future numbers sent you promptly, kindly give us a *continuing* order.

Economic Geology Publishing Co.
Urbana, Illinois, U.S.A.

THE JOURNAL OF GEOLOGY

a semi-quarterly

Edited by

ROLLIN T. CHAMBERLIN

Since 1893 a constant record of the advance of geological science. Articles deal with problems of systematic, theoretical, and fundamental geology. Each article is replete with diagrams, figures, and other illustrations necessary to a full scientific understanding.

$6.00 a year
$1.00 a single copy

Canadian postage, 25 cents
Foreign postage, 65 cents

THE UNIVERSITY OF CHICAGO PRESS

GIDDENS-LANE BUILDING

SHREVEPORT, LOUISIANA

CABLE ADDRESS: WILBAR

A New

QUESTIONS & ANSWERS SERVICE

for those Seeking Oil . . .

★ This department is operated to answer the questions of operators and geologists and others who may be interested in geophysics. It is our aim to stimulate interest in geophysics and to help the oil fraternity at large to gain a wider knowledge of the uses and limitations of the approved geophysical methods of finding oil. There is no cost and no obligation attached to this service.

Q. **Questions may be about any branch of geophysics, such as Seismograph, Torsion Balance, Magnetometer, Soil Gas Analysis, Gravity Meters.**

Questions may be on practical common sense problems.

Questions may pertain to any part of the world.

A. Answers will be furnished by the best qualified men on our staff; or, if we believe a geophysist outside of our organization should answer some particular question, we shall not hesitate to ask him to do so. Answers will be mailed at the earliest possible date.

Address Questions and Answers Department

INDEPENDENT
EXPLORATION COMPANY

POINTING THE WAY FOR THE DRILL

ESPERSON BUILDING HOUSTON, TEXAS

OIL MEN — *You are invited to send questions on geophysics to our Questions and Answers Department. Questions may be either general or highly specialized and may pertain to any part of the world. You'll receive a prompt and (we hope) interesting reply.*

Experienced in 21 States and in Foreign Fields

JUST OFF THE PRESS

PRACTICAL PETROLEUM ENGINEERS' HANDBOOK

BY JOSEPH ZABA, E.M.M.Sc.
Petroleum Engineer, Rio Bravo Oil Company
and
W. T. DOHERTY
Division Superintendent, Humble Oil & Refining Company

For a number of years there has been a growing demand for a handbook containing formulae and other practical information for the benefit of the man working in the production and drilling branches of the oil industry. So great has been this need that many engineers have tried to accumulate their own handbooks by clipping tables, formulae and figures from scores of sources.

The co-authors of this volume discovered by coincidence that each had been for a period of several years accumulating practical data which through their collaboration appears in this book. Both of them are men who have not only received theoretical training but who have had many years of practical experience as engineers in dealing with every day oil field drilling and production problems.

As a result of this collaboration of effort the publishers of this volume feel that it is a most valuable contribution to oil trade literature.

Its purposes are distinctly practical. The tables, formulae, and figures shown are practical rather than theoretical in nature. It should save the time of many a busy operator, engineer, superintendent, and foreman.

TABLE OF CONTENTS

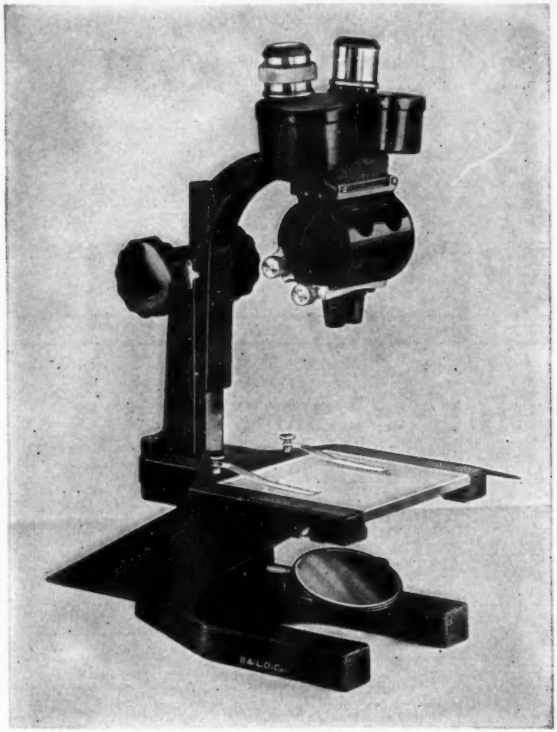
Chapter I—General Engineering Data
Chapter II—Steam
Chapter III—Power Transmission
Chapter IV—Tubular Goods
Chapter V—Drilling
Chapter VI—Production
Chapter VII—Transportation

Semi-Flexible Fabritoid Binding, Size 6 x 9, 408 pages—Price $5.00 Postpaid

Send check to

THE GULF PUBLISHING COMPANY

P. O. Drawer 2811 Houston, Texas



B & L

WIDE FIELD

BINOCULAR

MICROSCOPE

MEETS THE NEEDS OF THE GEOLOGIST

Wherever a stereoscopic view will increase the value of microscopical examination, the B & L Wide Field Binocular Microscope represents outstanding desirability and value. It is the complete answer to your specific needs in low power microscopy covering a range from 7 to 150 X.

In addition to an erect and unreversed three dimensional image, extremely wide field, long working distance, parfocal objectives, and the B & L Patented Drum Nosepiece, it has many other features that recommend it for the most exacting requirements. It has an extra long rack and pinion adjustment. The stand is heavier and more rugged. An inclination joint allows tilting to any convenient angle. Individual focusing tube compensates for variations in user's eyes. Glass stage mounted flush with metal supports gives larger working area.

Write for complete details to Bausch & Lomb Optical Co., 610 St. Paul St., Rochester, N.Y.

BAUSCH & LOMB

....WE MAKE OUR OWN GLASS TO INSURE STANDARDIZED PRODUCTION

FOR YOUR GLASSES INSIST ON B & L ORTHOGON LENSES AND B & L FRAMES...

WE BANK ON OIL
1895 — 1938

THE
FIRST NATIONAL BANK AND TRUST COMPANY
OF TULSA

THE GEOTECHNICAL CORPORATION

Roland F. Beers
President

902 Tower Petroleum Building
Telephone L D 711 Dallas, Texas

Verlag von Gebrüder Borntraeger in Berlin und Leipzig

Einführung in die Geologie, ein Lehrbuch der inneren Dynamik, von Professor Dr. **H. Cloos.** Mit 1 Titelbild, 3 Tafeln und 356 Textabbildungen (XII und 503 Seiten) 1936 Gebunden *RM* 24.—

Das Buch will den überreichen Forschungsstoff der letzten Jahrzehnte so darstellen, daß sich auch Fernerstehende von dem Bau, der stofflichen Zusammensetzung und den Bewegungsvorgängen in der Kruste unseres Planeten ein Bild machen können. Die Darstellung geht überall von den Tatsachen und zwar, so weit wie möglich, von den tatsächlichen Bewegungen aus und endigt bei ihrer gedanklichen Auswertung. Auf die Interessen der Praxis, besonders des Bergbaus, ist überall Bezug genommen, die Verbindung mit dem Leben nach Möglichkeit ständig gewahrt. Das Buch sollte auch den nicht mit gelehrtem Gepäck belasteten Wanderer im Gebirge führen können.

Die Beispiele stammen aus allen Teilen der Erde, nicht zuletzt aus Skandinavien, Indien, Nordamerika und Afrika. Aber Deutschland und seine früheren außereuropäischen Besitzungen sind bevorzugt.

Für den Verfasser gibt es in der Erde keine Einzeldinge und nichts Fertiges. Er versucht, die Tatsachen in ihren Zusammenhängen vorzuführen (Bewegungen, Kreisläufe, Abstauungen, Entwicklungen usw.), und möchte alle Erkenntnisse aufgefaßt wissen als Pflastersteine in einer Straße zur Lösung eines letzten, zentralen Problems der Gesamterde. Lücken in diesem Pflaster werden nicht überkleistert, sondern deutlich umschrieben. Das Buch will also nicht nur in seinem Stoff ein dynamisches sein.

Ausführliche Einzelprospekte kostenfrei

A WORLD WIDE EXPERIENCE

Embracing the discovery of over 38 NEW OIL FIELDS

AT YOUR SERVICE

WRITE FOR A COPY
OF THE SSC BLUE BOOK

Seismograph Service Corporation

KENNEDY BUILDING TULSA, OKLAHOMA, U. S. A.

For

SEISMOGRAPH RECORDS

use

EASTMAN RECORDING

PAPERS

PREPARED DEVELOPER

AND FIXING POWDERS

Supplied by

EASTMAN KODAK STORES, INC.

1010 Walnut Street, Kansas City, Mo.

1504 Young Street, Dallas, Texas

"Petroleum"

Magazine for the interests of the whole Oil Industry and Oil Trade.

Subscription (52 issues per annum) $18

"Tägliche Berichte über die Petroleumindustrie"

("Daily Oil Reports.")

Special magazine for the interests of the whole Oil Industry and Oil Trade

Subscription: $40

VERLAG FÜR FACHLITERATUR Ges.m.b.H.

BERLIN SW. 68, Wilhelmstrasse 147.

VIENNA XIX/1, Vegagasse 4.

THERE'S A BAROID PRODUCT

for every step in drilling

SPUDDING-IN

CEMENTING CASING

LOST CIRCULATION

SALT OR SALT WATER FLOW

CAVING FORMATION

HEAVING SHALE

GAS OR UPPER PRODUCTION ZONE

CEMENT-CUT MUD

DRILLING-IN

BAROID PRODUCTS

BAROID—Extra-Heavy Colloidal Drilling Mud. • AQUAGEL-Trouble-Proof Colloidal Drilling Mud. • STABILITE—An Improved Chemical Mud thinner. • BAROCO—An Economical, Salt Water-Resisting Drilling Clay. • FIBROTEX—For Preventing or Regaining Lost Circulation in Drilling Wells.

Stocks Carried and Service Engineers Available in all Active Oil Fields

BAROID SALES DEPARTMENT

NATIONAL PIGMENTS & CHEMICAL DIVISION

NATIONAL LEAD COMPANY

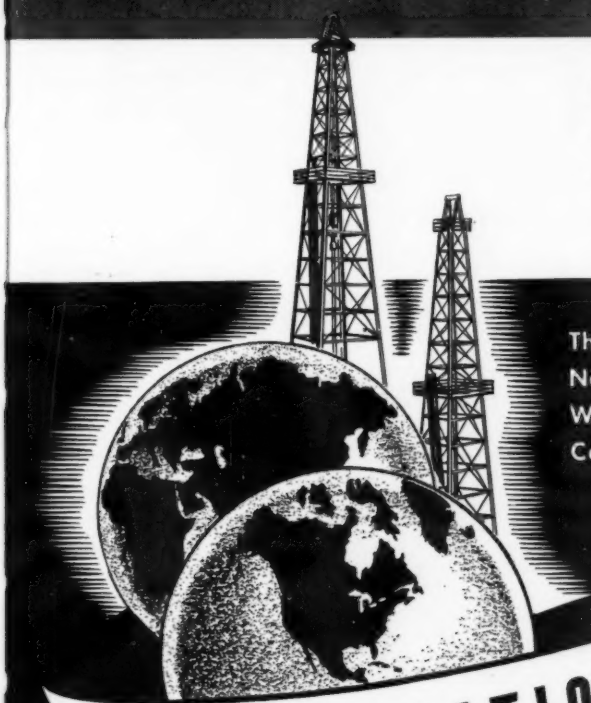
BAROID SALES OFFICES—LOS ANGELES • TULSA • HOUSTON

IGI

ACCURATE • ECONOMICAL • EFFICIENT

THE *Jakosky* ELECTRICAL METHOD OF GEOPHYSICAL EXPLORATION

For Mapping Structures, Locating Faults, General Reconnaissance



New exclusive continuous-recording process now provides speed, detail and accuracy of measurements never before achieved. The cost is surprisingly small.

This Method Protected By U. S. Patents Nos. 2,105,247-2,015,401 and 1,906,271 With Over 10 U. S. Patents Pending Covering Apparatus And Method.

INTERNATIONAL GEOPHYSICS INC.

ORGANIZED IN 1929

1063 GAYLEY AVENUE
LOS ANGELES, CALIFORNIA

SOIL ANALYSIS SURVEYS

The Smith System of Soil Analysis Surveys offers a valuable aid to the geologist and geophysicist. This system is the result of 10 years research work and has been in commercial use for more than 4 years.

For further information, see the article printed in The Oil and Gas Journal, issue of June 23rd, 1938, or write for a reprint.

Particulars and cost estimates furnished without obligation.

GEOLOGICAL SCIENTIFIC SERVICE CO.

ROBT. O. SMITH, PRESIDENT

416 PETROLEUM BUILDING FORT WORTH, TEXAS

HOUSTON OFFICE: 703 SECOND NAT'L BANK BLDG.

Originators . . .
OF CONTROLLED DIRECTIONAL DRILLING

Pioneers . . .
OF OIL WELL SURVEY SERVICE

Eastman
OIL WELL SURVEY CO.
DALLAS, TEXAS
DIVISION OFFICES: DALLAS, HOUSTON, OKLAHOMA CITY, LONG BEACH
Service Branches: [illegible]

BACK NUMBERS AT HALF PRICE

Members and associate members of the Society of Economic Paleontologists and Mineralogists and of the Paleontological Society and subscribers of the

JOURNAL OF PALEONTOLOGY

will be privileged for a limited time to purchase complete Volumes 2 (1928) to 11 (1937) at the very special price of Three Dollars ($3.00) per volume. This offer represents a 50 per cent discount from regular prices and gives opportunity that should not be overlooked. Furthermore, only part of the supply of back volumes will be sold at this price. The stock of Volume 1 is exhausted, but any others can be purchased. Place order promptly if you wish to secure discount because this offer will be withdrawn as soon as allotment of copies is exhausted.

Separate numbers from broken sets of back volumes will be sold to members, associate members, and subscribers at the special price of Twenty-Five Cents ($0.25). This offer is open only while the supply lasts. Available at present are: Vol. 2, Nos. 2, 3, 4; Vol. 3, Nos. 1, 2, 4; Vol. 4, Nos. 3, 4, and Supplement; Vol. 5, Nos. 1, 2, 3; Vol. 6, Nos. 2, 3, 4; Vol. 7, Nos. 3, 4; Vol. 8, Nos. 2, 3, 4; Vol. 9, Nos. 1, 3, 4, 5, 6, 7, 8; Vol. 10, Nos. 1, 4, 5, 6, 7, 8; Vol. 11, Nos. 3, 4, 5, 7, 8.

Members and associate members of the Society of Economic Paleontologists and Mineralogists and subscribers of the

JOURNAL OF SEDIMENTARY PETROLOGY

may purchase, for a limited time, complete Volumes 1 (1931) to 7 (1937), at half price, One Dollar and a Half ($1.50) per volume.

Separate numbers from broken sets of back volumes will be sold to members, associate members, and subscribers at the special price of Twenty-Five Cents ($0.25). Available at present are: Vol. 1, No. 2; Vol. 2, Nos. 1, 3; Vol. 3, Nos. 1, 3; Vol. 4, Nos. 2, 3; Vol. 5, Nos. 1, 2; Vol. 6, Nos. 1, 3; Vol. 7, Nos. 2, 3.

All prices, postpaid

Send orders to

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

Box 979, Tulsa, Oklahoma

G.S.I. in MARACAIBO

WORLD WIDE EXPERIENCE

THROUGH ACHIEVEMENT YOU KNOW THIS COMPANY

GEOPHYSICAL SERVICE · INC

REFLECTION SEISMIC SURVEYS DALLAS TEXAS

The above photograph shows a core taken with a Hughes "Type J" Core Bit on the Thomas No. 3, Parr Ranch, in Duval County, Texas. It's the kind of core you need—it's the kind of core you get with Hughes Core Bits.

HUGHES TOOL COMPANY • HOUSTON, TEXAS, U.S.A.